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THE THOMAS YOUNG ORATION:

"CONTRIBUTIONS TO THE HISTORY OF THE SPECTACLE TRADE FROM THE EARLIEST TIMES TO THOMAS YOUNG'S APPEARANCE"

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Delivered, 27th November, 1923

IT is a special honour for me to have been asked to deliver the Thomas Young Oration this year, the one hundred and fiftieth after his birth. The subject I have chosen bears some connection with Young's work in physiological optics.

For our lecture Thomas Young comes before our mind's eye for a twofold reason: in the first place because he constructed his improved optometer in order to facilitate the finding of the correcting glasses for ametropic patients; in the second because he not only mentioned the use of divided (bifocal) glasses at a very early date, but was the first to apply them to scientific purposes.

With regard to the astigmatism of the eye, he certainly discovered and measured this fault, but did not try to correct it in the modern manner: the scientific treatment of this spectacle problem was left to G. B. Airy's genius, as the whole question of astigmatic glasses becomes important in the 19th century only.

To-day we must restrict ourselves to our historical problem and deal with spectacle glasses of a simpler form. In order to obtain a clearer view of the contents I have divided our subject into six coherent parts. At the end of the paper I give the sources for my different statements, thus helping any future historian of our subject to ascertain the novelty of his results, and I wish expressly to point out every hypothesis I shall have to make.

I. *Some remarks on the earlier spectacle history* (before 1500)

Spectacle glasses have evidently been developed in consequence of the experiments with lenses in general. Unfortunately our knowledge concerning the first attempts at such experiments is very slight, as the most important work(1)* on optics in the Greek language, the ὀπτικὴ πραγματεία of Claudius Ptolemaeus (about 150 A.D.), has not been well preserved and shows a gap in this very part; it mentions, however, the magnification exerted by a convex surface on an object lying in the denser medium at a greater distance from the vertex than the radius. But as the Arab optician(2) Ibn al Haitham (the Alhazen of the Middle Ages; he died in 1038 A.D.), who in different parts of his book shows Ptolemaean influence in a marked manner, knows something about plano-convex lenses with a thickness greater than the radius, we may suppose, not without reason, that such knowledge was really of Greek and especially Ptolemaean origin. It is quite possible that later on such clumsy magnifiers placed on a minutely-written manuscript were used by weak-eyed monks, and independently at different places, as we are aware that a Latin translation of Alhazen's work, the *Opticae Thesaurus*, was well known in many convents(2). About the time of this translation (1266) Roger Bacon, in his *Opus Majus*(3), treated the same Alhazenic problem and advised taking a plano-convex lens with a thickness smaller than the radius; he recommended this in order to help old and weak-eyed people. Such a lens was made of crystal or glass and it was to be used resting on the page, the letters of which were to be magnified. Thanks mainly to R. Greeff's investigations(4, 5, 6), we are now aware that between 1260 and 1284 German mediaeval poets mentioned at least in three different places a certain optical magnification effected by lenses. At this time one knew how to grind crystals in such a way that they magnified small characters, if placed on the manuscript. As in the third quarter of the 13th century this was a contrivance of such regular occurrence that it was mentioned in poems written in the language of the country, we must conclude that the first manufacture of these lenses is to be dated back considerably, at least to the first half of the 13th century. Such early hints of the optical magnification are at present known from German mediaeval poetry only, but I have no doubt that they will be found in other languages as well, if sufficient attention be given to this fact. At one place, possibly the oldest reference(4), the instrument was called a lichter Spiegel, i.e. clear lens. It is possible that in other surroundings these lenses were preferably called *berylli* after some natural transparent mineral (*berillus* = βήρυλλος). As far as I know, this expression gave rise to the Dutch word "den Bril," and it migrated to Germany as "der Brill." I may as well mention that I have found an explanation of the French word "bésicles"; it appears to be derived from the same root and the older form "bericles." In good accordance with this, G. Albertotti in his later papers(7) points out the distinction between such reading glasses and the spectacle glasses proper. Such were probably held to the eye by the hand and took their name "oculare," "occhiale," from the eye. We must therefore look upon the first real spectacle-helps as one-eyed glasses with a handle, and fortunately the oldest picture of eye-glasses (painted at Treviso in the year 1352) shows this form together with another, in which the handles of two one-eyed glasses are riveted together.

As all languages spoken in countries where spectacles were applied in early times show the peculiarity of using for this binocular eye-help a word in the plural number, we may explain this as some relic of the fact that two single eye-glasses had to be combined in order to form the new binocular instrument. This must have been done before the year 1352, but the new custom had not then totally replaced the old one-eyed form. G. Albertotti is of opinion that spectacle glasses proper were made in Venice during the last half of the 13th century, and I think this likely enough, especially as the valuable material of Murano glass or crystal was near at hand. In R. Greeff's reprints and translations (8, 9) of the Venetian crystal-workers' by-laws, between 1284 and 1326, expressions, which must be translated as eye-glasses, do occur in different places. But on the other hand the spectacle makers at Venice had then evidently not separated themselves from the crystal-workers, and we must perhaps infer that in these early times the spectacle industry was not yet of considerable economic moment. The fact that Dante (1265–1321) in his poem does not mention spectacles proper and their use is in agreement with this supposition, although we know, from such a reliable source as Bernard de Gordon's work, the *Lilium Medicinae*, of 1303, of their application in these times.

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* The small numbers in the text refer to the list of sources and references at the end.

In the Netherlands (Haarlem) spectacles (10) are said to have been used from the beginning of the 14th century, and as later on we know of a well-developed spectacle industry in the Low Countries, we may infer that it had an early beginning. But, unfortunately, all details of the oldest manufacture are conspicuous by their absence both in Venice and in the Low Countries, and we are compelled to form a kind of image from casual notes and from pictures. We must express the hope that researches and studies in the Venetian and Dutch Archives may bring to light more details concerning the early history of this craft; and our hope is the more confident, as in the last years our knowledge of the later stages of the spectacle industry has been most happily enlarged by archival studies, as we soon shall see.

Very probably the older spectacles were of collective effect. But Nicolaus Cusanus (1401–1464) mentions in his treatise, *De Beryllo* (11), negative lenses as well. If R. Greeff is correct in dating this publication between 1430 and 1440, we may state that negative spectacles were known in the first half of the 15th century; they will, therefore, have been made somewhat earlier.

Our present very defective knowledge of these oldest spectacles has been derived mostly from pictures, and it is only natural that we are better informed with regard to the mountings than with regard to the glasses. The above-mentioned riveted spectacles had been in use for a considerable time, undoubtedly up to the beginning of the 16th century and in a less conspicuous form, as "hinged spectacles," even to the first years of the 18th century. In any case such an instrument was fastened on the nose. In very early times, however, improvements were made, especially in two directions, towards greater ease in wearing as leather spectacles, and towards a more elegant appearance as bow-spectacles (Bügelbrillen).

The former must have been very widely spread, even after the year 1500, as the greater number of the oldest specimens in the larger collections show such leather mountings for spectacles of the first half of the 16th century. They are expressly mentioned in the by-laws for Regensburg and Paris. In J. Amman's picture of 1568(12) the spectacle maker is represented as preparing leather mountings. Daza de Valdes recommends them in 1623 to his Spanish countrymen as being very easy to wear although of a rather unbecoming appearance. In the old English handbill(13) with the sign of Archimedes and the three golden spectacles, as F. Morgan printed it before 1744, probably retaining a much older form of sign, I think I recognize leather mountings, and the old motto written on them "The Right True," may have once served to warn customers against more elegant but inferior innovations. We may infer from this similarity that the spectacle industry on this side of the Alps, if not derived from a common origin, grew up under a certain mutual influence; either the products were largely imitated, or migrating journeymen brought the art of one place to the other.

The more elegant and lighter bow-spectacles are depicted on different portraits of the 15th century, and A. v. Pflugk(14) is able to give other evidence of such forms of Italian origin between 1431 and 1446. The material for these forms seems to have been preferably horn taken from the horns (not hoofs) of oxen; if they were really made of bone at first, as we may gather from different old sources, the craft on this side of the Alps seems to have soon discarded it in favour of horn. The precious metals were used in spectacles for princes and nobles, and we have a French list of references(15) to such specimens, compiled in 1853. For the time before 1500 it contains news of thirteen such costly pieces; three of them are single glasses. Although we are transgressing on the time boundaries of this part of our lecture, we may here insert A. v. Pflugk's story(16) of the golden spectacles made for August, the elector of Saxony (1526–86). He was a very sumptuous prince and paid 50 Reichs-Thaler (about 12 guineas) for a Venetian pair of spectacles with gold mountings. It will interest you to know that having heard of quadrilateral spectacle lenses made in London he ordered some of them; and when he obtained them after long delay, the cost(17) for "some spectacle lenses" was 12 Reichs-Thaler (£3), to which 5 Reichs-Thaler (£1. 5*s.* 6*d.*) were to be added as freight. We see that at that time London fashion gave quite a peculiar shape to special spectacle glasses, and that the price was amply sufficient. Unfortunately no further information as to these glasses is forthcoming.

II. *The development of the spectacle industry in South Germany's Free Towns during the 16th century*

O. Hallauer(18) is probably right in supposing that spectacles became necessary for a greater number of people—in less affluent circumstances—only after the invention of printing, in other words after 1440. If we accept this view, we have one reason more for the rapid development of the spectacle industry in South Germany during this time.

From A. v. Pflugk's writings(19) we know that the first spectacle makers are reported from Frankfurt a.M. in 1450, from Strasburg in 1466, and from Nürnberg in 1478, that is more than 150 years after mention of the reading glass in Manesse's collection. As in all these instances spectacles are invariably designated with a name derived from the word beryl, we may perhaps infer that this industry made its way from the Netherlands towards the East and the South-East. It probably came about the same time to Regensburg (Ratisbon), although we have no earlier evidence of this than about 1560, but from the importance of the Regensburg spectacle industry of that time we must infer an earlier beginning. The convenient situation of the glass factories in the Bavarian and Bohemian Forests furnishes an explanation of the indubitable fact that the manufacture of spectacles developed deep and lasting roots in these industrial towns.

As far back as 1492 and 1495 we are acquainted with the price (20, 17) of spectacles bought at the South Bavarian convent, Tegernsee, where a pair of negative spectacles was purchased for about the sum of 7 farthings. Although we are not expressly told that these spectacles came to Tegernsee from the adjacent Free Towns, we may safely assume this, as in consequence of the difficulties of transport in those times goods of such cheapness could be distributed over a very short distance only.

Fortunately our knowledge does not depend on such casual observations, but we have here—otherwise than at Venice and the Netherlands—early substantiated laws and by-laws of the spectacle makers' guilds, of which we now have to speak.

A. v. Pflugk's investigations (21) have thrown a very curious light on an old statute found recently among the archives of Regensburg. A manuscript copy, dating between 1510 and 1520, is preserved there of a statute not belonging to a particular city but to a community of towns. The text is written in the dialect spoken in this region, and the fines imposed upon transgressions are given in Nürnberg coin, but it is possible that we have before us the translation of a foreign and (up till now) unknown original. It contains, among other material, laws concerning the time of apprenticeship, the master pieces*, the number of journeymen and apprentices, the prohibition of outside and unskilled labour, the exacting of good and conscientious execution. There is no doubt that its principal object was to bring all the different masters of the craft under exactly the same conditions, so that especially the underselling of cheap and nasty goods was heavily punished. I do not think it impossible that this statute also came from the Netherlands, but have no evidence of this.

In any case the craft in the South German Free Towns seems to have developed its constitution on this basis, and we may point out two principal directions, one taken at Nürnberg, the other at Regensburg.

At Nürnberg the High Council—an aristocratic governing body—prohibited the development of the spectacle makers' union into a free or sworn guild (geschworenes Handwerk), only granting them the lower status of a "closed craft" (gesperrtes Handwerk). The journeymen of such a craft were not allowed to leave Nürnberg in order to extend their knowledge by working at other places, but the council tried to preserve industries of this kind as monopolies to Nürnberg alone. We cannot wonder that such journeymen of a secondary order frequently tried to desert and to settle in neighbouring places under better conditions. The laws and by-laws of Nürnberg (22) relating to our present enquiry are to be found in the collection (not in the best order) of the different decrees issued by the High Council. In order to form a judgment concerning the value and tendency of the Nürnberg legislation as regards the spectacle industry, it has been necessary to bring all these decrees under different headings (23).

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* The term "master piece" ("Meisterstück") was used to designate the piece of work carried out by a workman (Geselle) to enable him to graduate as a "master."

At Regensburg (24, 25) we find the masters forming a free guild with a charter, written about the middle of the 16th century and quite exemplary as regards order and system; the mounting of the spectacles has been especially well treated. We shall have to speak of this part presently.

As to the distribution of the ready-made goods, we must infer from other countries and other periods that it fell exclusively to pedlars. We may suppose that very early some designation as to the wearer's age was attached to the individual pair of spectacles. In the case of the Tegernsee glasses we read of "young" spectacles. Later on it became usual simply to scratch the number of years on the margin, as we are told (26) by the Messinese Abbot Maurolycus (1494–1575) that such was the custom in the time of his youth, which brings us back to the beginning of the 16th century. This custom (according to which *stronger* collective lenses were called *older* lenses) seems to have taken very deep root, and R. Sutcliffe (27) has preserved a remarkable testimony of its existence in England as late as during the sixties of the last century. That this system had its practical value for a time so remote as the 16th century is easily understood, as the pedlars, who sold a quantity of other goods as well, cannot be supposed to have been gifted with anything but indifferent optical insight. In such a way the spectacle makers scarcely ever came into personal touch with the buyers. We cannot but deplore this circumstance, as this also tended to the development of a large manufacture of uniform unadaptable spectacles.

By a lucky chance we know of a pair of reading spectacles bought by the painter Albrecht Dürer (28) in the Low Countries in 1520–1 for about 9½ farthings, and we see by that glimpse into the otherwise unknown world of the westerly craft that there the retail prices were about the same as thirty years earlier in Tegernsee.

Turning now to the statute (22), we must point out that the old undated copy has certainly had its influence, as the master pieces (consisting of two horn spectacles, one pair for distance and one for near sight, in perforated work of different colour) remained practically the same in Nürnberg up to 1723. Some Regensburg influence as to the outer form is to be noticed in the course of more than two centuries, but these master pieces were of a somewhat stereotyped character, in no wise connected with the ordinary day's work. Regarding this we very early notice a tendency towards the division of labour: as soon as 1507 there were special glass workers working for the community of spectacle makers; later on we distinguish Glasreiber, i.e. glass grinders, and Stückwerker, i.e. piece workers. We may here notice that the grinding process (dry grinding on stationary tools) was executed in the old manner, that afforded imperfect work only, being at the same time very dangerous for the workman.

The decrees in their proper order of time and subject provide us with remarkable insight into the daily wants of this craft: the fluctuations of trade rendered conspicuous by restrictions on the taking of apprentices, the difficulty of hindering journeymen from deserting, Regensburg's serious competition, the equalization of the journeymen's payment, the number of journeymen and helps; all these are questions which had to be brought before the High Council. Some of them are specially important for our present subject, for example, the prices of the goods in the year 1583: we see that in buying

5 dozen ordinary leather spectacles the price was 4 farthings a pair,
2 ,, gilt horn spectacles the price was 9½ farthings a pair,
6 ,, ordinary horn spectacles the price was 3 farthings a pair,
6 ,, single glasses in horn the price was 3 farthings a piece.

It is possible that in the last case the glasses had sometimes a negative focus. These being wholesale prices, the pedlar will have charged more, and it is likely that the comparatively great difference between this and Dürer's price—about 3 farthings as against 9½ in his case—is to be accounted for by the retailer's trouble.

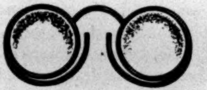


Fig. 1.

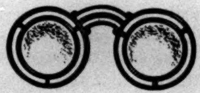


Fig. 2.

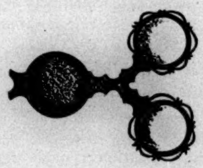


Fig. 3.

Fig. 1. Spectacle frame with elastic side parts.

Fig. 2. Spectacle frame for adapting small (strong) lenses to wearers with comparatively wide interocular distances.

Fig. 3. Folding hand frames (Weiser); see Fig. 6 for method of holding them.

Spectacle frames of Regensburg manufacture (about 1560); all taken from Refs. (24) and (37).

It was quite different at Regensburg (24), as the spectacle makers there formed a free guild and developed their elaborate laws, probably about the middle of the 16th century, in a very methodical and orderly manner. With regard to the master pieces, the old prescriptions of the perforated spectacles were not abolished, but they now formed but the twelfth part of the whole task; the would-be master had to make all the necessary tools for the different spectacles forming the master piece as well, in order to pass his examination.

The description of the master pieces is very minute, and we find some elaborate directions, with copious illustrations besides, from which we may form a favourable impression of the exactness and gift of invention of the Regensburg workmen. Figs. 1, 2, and 3 are taken from this illustrated edition and they will show you the remarkable result with which they had succeeded in the second half of the 16th century in increasing the elasticity of the horn mounting in order to adapt to the nose the lighter horn frame as easily as the clumsier leather frame. Nose spectacles were then distinguished from folding hand spectacles (Weiser = clock-hands), in which the fingers holding them had to be placed at the front, as Fig. 6 will show. There were also aiming spectacles mounted on rifles for ametropic marksmen.

Bringing all the designations for the effect of the glasses together, we obtain from the Regensburg by-laws twelve different expressions, of which six may have belonged to myopic and six to hypermetropic wearers. The evaluation in numbers of our modern system was not possible; I should only insist (30) that young glasses meant dispersive and old glasses collective lenses, and that the idea of lessening the effect by subtraction and heightening it by addition of lenses of the same sign was perfectly familiar to the old workers. I have only once (29) come across something like a numerical value, and it is possible that this number refers to the diameter of the grinding bowl measured in Regensburg inches. But, as these measurements belonged to the inner service of the factory, their knowledge does not seem to have been laid down in any description for the public and has therefore become lost to us.

Most widely spread were weak collective lenses for distance spectacles used by elderly people, and the old craftsmen seem to have looked upon hypermetropia in elderly eyes as quite the average state.

The rules for forming the perforated spectacles as a part of the different master pieces were laid down (25) with special care, clover leaves, acorns, hearts and crownlets being the principal forms of the decoration, as you will see in Fig. 4, taken from the additional illustrated directions (and reconstructed from them). All these details surrounded the Regensburg arms, two large (St Peter's) keys and a capital R. A Nürnberg model is shown in Fig. 5. In a later chapter we shall devote some little space to the description of the manner in which Nürnberg followed the Regensburg example in the period when the craft there became more and more stereotyped.

In general we may point out that the object of providing cheap spectacles for extensive circles of the population and the application of division of labour to that end was praiseworthy; the spectacle industry could not have flourished without such a safe foundation. But it is to be deplored that no steps were taken for improving the old, very primitive means of grinding and polishing.

The materials for the spectacle mountings at that time seem to have been rather exclusively leather and horn. J. Amman's woodcut (12, 31) of the year 1568 of a Nürnberg master at his work (Fig. 6) principally shows leather mountings and only one horn mounting in the form of a folding handglass (Weiser), which the buyer is trying on in the manner spoken of above. If the description of the Ambras collection mentions metal-mounted spectacles of German origin bought towards the end of the 16th century, it is not safe to contradict, but I have been unable to find any reference to such mountings in books or writings of that time. They were perhaps rather rare.

The master signs*, not infrequently found on old leather mountings, have been

* The term "master sign" was used to designate a stamp for a mark or brand which was given

studied (19) with the greatest diligence by A. v. Pflugk, as far as Nürnberg craftsmen are concerned. Although this practice was universal for all the Free Towns and their spectacle industry (necessarily so during a time when reading was not in everybody's power), by far the best testimony for it has been preserved at Nürnberg. There the general custom was enforced by a decree and has been observed from 1561 downwards, but I shall reserve the collection of such signs to show you in a later part of this lecture.

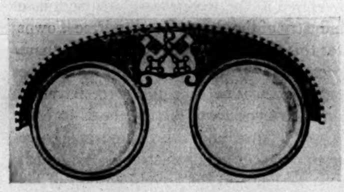


Fig. 4. Reconstructed Regensburg model; taken from Ref. (25).

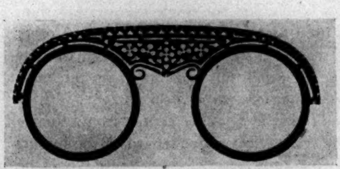


Fig. 5. Extant Nürnberg model (in A. v. Pflugk's collection) also taken from Ref. (25).

Perforated horn frames for master pieces.

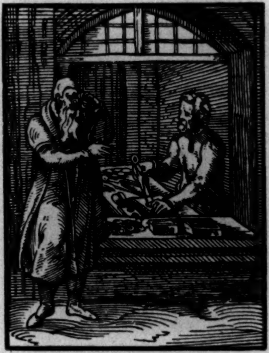


Fig. 6. Nürnberg master at his daily work; taken from Ref. (12).

III. *Limited knowledge regarding the Venetian craft in this period*

As already observed, we have no detailed knowledge as to the development of the spectacle industry in Venice, although its early appearance admits of no doubt. I am therefore reduced to the necessity of collecting information about that old centre from secondary sources. From Maurolycus' statement referred to above we may infer that the Venetian craftsmen used to designate their spectacle lenses with the wearer's age at least as soon as the first quarter of the 16th century.

Corroboration of the importance of this industry may be obtained from the Nürnberg decrees; since 1577 Venetian spectacles only (22) were allowed to be sold by pedlars and other tradespeople in the streets of Nürnberg, whereas in that town the home products were allowed to be sold at the respective manufacturer's shop only. In an old booklet (32) of 1592 we read of a small pedlar near Frankfurt

to the journeyman after he had passed the examination and paid the prescribed fees for becoming a master; all his work had to show his master sign.

announcing his spectacles as specially praiseworthy as being of Venetian origin. They must have been therefore of a low price comparable with that already cited for the Nürnberg and Dutch spectacles.

If we try to explain the reason for such an attitude being taken by the Nürnberg High Council towards the Venetian merchandise, we think we may find the explanation in the quality of the Venetian glass (made at Murano, near Venice). As this glass was evidently under the Venetian government's control, and as it was necessary for some of the spectacles enumerated in the Regensburg description, it was of great importance to the spectacle industry of the South German Free Towns to have free access to this material, and for this reason their government may have dealt so amicably with the Venetian spectacles. We do not know whether the Nürnberg eye-glasses were similarly treated in Venice; perhaps not, as the Bavarian or Bohemian glass works on the other hand were not controlled by the Nürnberg authorities. That the Bavarian glass was well known and appreciated in Venice follows from different and independent testimonies of about this time. We find it mentioned by T. Garzoni(33) in 1585, by J. B. Porta in the second edition of his *Magia Naturalis* in 1589, and by H. Sirturus(34) in 1618. According to Porta's statement, it is not improbable that there was at that time a regular glass trade across the Alps. As the German glass was blown and the single piece rather thin, it was, according to Sirturus, preferably used for dispersive lenses. On the other hand there are technical terms in the Regensburg statute(25) from which we may gather that the Murano glass was chosen especially on account of its thickness (Blocklinsen). Pebble was also used at Venice at least so far back as 1585.

No particulars about the factory conditions in, and the export from, Venice are known to me with the exception of the two notices above regarding the import into Germany during the 16th century. Our knowledge of these times would be much advanced if official documents of this kind should turn up in the Venetian Archives. For the present we must suppose that the countries surrounding the Mediterranean ordered eye-glasses from this industrial centre, and that the Spanish colonies will have bought spectacles as they later on bought Venetian telescopes. Whether the signs, mentioned by Garzoni, of "the large Eye-glass" and of "the Angel" were master signs as well as street signs is not known; we have at present no knowledge of Venetian master signs, although we should suppose, that such signs(35) might have been of great use to the trade.

For our subject, however, the principal importance of the Venetian craft lies in the treatment of the glasses, especially in the numbering. From Garzoni's short remarks we know that the craft was able to measure the influence of the glass material on the power of the ready-made lens, and we must therefore conclude that, considering the time, the measuring apparatus was of remarkable exactness. Further, we know from the same source that the Venetian craftsmen, like their South German colleagues, were aware(25) that two weak lenses added together were of the power of one stronger lens, and that the power of a strong one could be halved by subtraction of a weak lens. Remembering this, it does not seem impossible that the Venetian craftsmen had chosen a certain lens as unit and, by putting two, three, four, etc., such units behind each other, had developed a scale according to the *power* of lenses. If our supposition be correct, they had founded a similar system to the modern one accepted in 1875 for international use, where the lens of the power

$$1/1\text{m} = 1 \text{ dioptre}$$

is the unit. Garzoni's lens numbers may be grouped in such a way and his unit was perhaps equal to 0·6 D. It is possible that the power of any given lens was determined by means of the magnification (or diminution) exercised on a certain measuring mark.

Such a system is indeed known to us from a book published somewhat later, that is in 1623, when a Spanish author, B. Daza de Valdes, describes it. In the French translation (36), the only version of it I know, he made some mistakes as regards the use of the measuring scales, and I am therefore of opinion that he had perhaps not invented but only taken over this system. Taking into account the close connections then existing between Spain and Italy, I do not think the hypothesis too bold that Daza's system was worked out on the basis laid down by the old Venetian factories and their experience of 300 years or more. Further I should not consider it impossible that such a system was brought over the Alps as well and served as means for distinguishing the twelve different steps or distinctions in use at Regensburg. But I have no evidence of this.

In any case we must credit the old Venetian craftsmen with a good knowledge of the requirements of an optician, especially when we take into account the long duration of their experience. I may mention here that M. A. de Dominis, whose optical treatise was published in 1611 in Venice, evidently knew something of the best forms of spectacle glasses. He distinguished plano-convex and plano-concave lenses and conscientiously put the spherical surface of the collecting glasses towards the object, of the dispersive lenses towards the eye.

As Daza de Valdes in 1623 gives the same rule, and as in the surviving Nürnberg master pieces between 1608 and 1721 the plano-convex glasses are placed in accordance with it, we shall not be far wrong if we credit the Venetian craftsmen with this knowledge, although it is an hypothesis only. Perhaps we could point to the clever and active exploitation of the Dutch telescope in Venice in order to make the above supposition more allowable.

Venetian practice in mounting spectacles remains, as far as our knowledge goes, decidedly behind that of the Regensburg craft. If Garzoni was not misinformed by his instructor, the Venetian spectacles were mounted in bone mountings in 1585, whereas in the respective countries on this side of the Alps bone had been extensively replaced by leather and horn, and the metal mounting was in progress.

IV. *The spectacle development in Spain*

Even somewhat before Garzoni's book, that is to say during the lifetime of August, the elector of Saxony (who died in 1585), we hear of a kind of spectacles, at the same time expensive and comfortable, which were made (16) for this sumptuous prince by a Spaniard. Such a single notice has not much weight, as it might be the tale of the remarkable dexterity of some special artisan, but soon after the testimonies multiply, and we must suppose that spectacles were specially valued in Spain. Preserving chronological sequence, we may point out that the renowned painter El Greco (Domenico Theotokopuli, born between 1545 and 1550, died 1614) in 1596 painted the Spanish Cardinal Nino de Guevara with large nose-spectacles held by threads on the ears. Evidently this high clerical dignitary used to wear his glasses continually. It may have been about the same time that Spanish-Italian Jesuits as missionaries in the far East introduced these thread-spectacles even into China, teaching the Chinese their manufacture. The fact itself has been related in an historical treatise written by Jesuits about a century later. That these spectacles, which may have been the form best adapted to Mongolian faces, were and remained popular in China, cannot be doubted: quite a number of travellers bore testimony (37) to this from the beginning of the 19th century onwards, although they did not know anything of the above development. The Chinese have improved upon the old Spanish form by adding a front rest to it, and it seems that this improvement has also been accepted in Japan.

Quite an explicit paragraph about the Spanish custom of wearing glasses in public has been written by the above-mentioned Hieronymus Sirturus, a Milanese. The few details that are as yet known about his life shall be given here according to R. Greeff (38). We learn from this source of three books written by him: the first published in 1614 on public law and similar subjects, the second published in 1618 on optical matters, especially the telescope, and the third published in 1638 as a memoir in Italian, dedicated to G. Baita. Every one of these was printed in Frankfurt a.M. According to Count C. A. Manzini (39), Sirturus seems to have been still alive in the spring of 1660. He himself mentions having published the plan for his optical book as early as 1612, having travelled between 1609 and 1611 in order to collect knowledge with regard to the Dutch telescope patented in the autumn of 1608. Supposing him to have been twenty years old in 1609, we conclude that he probably lived from 1589 to 1660, a period which is by no means impossible. This somewhat mysterious personage tells us that at his time spectacles were immensely popular in Spain, as spectacle wearers were supposed to look more important and dignified. The weakest number of collective glasses bore the Spanish designation *vista commun* even in Italy; it seems to have had a power of 1·5 D. Sirturus mentions having made the personal acquaintance of the man who introduced the art of spectacle making into Spain. If that be really the case, it had a remarkably quick growth in that country. In his time, so he was informed, Barcelona was the place where the Spanish spectacles were made.

In agreement with many statements made by Sirturus are the remarks of a Spanish author of nearly the same time, the licentiate B. Daza de Valdes, whose book appeared in 1623 in Seville; my knowledge of it is derived from the French translation (36), finished in 1627, which was published 265 years later by G. Albertotti. Here we find the first treatise on spectacles in a modern language, and it serves as one of the strongest proofs imaginable for the high value attached to its subject in Spain, as no other country at that time showed sufficient interest in spectacles to bring out a similar book. In two different places (30, 31) I have written about Daza's optical knowledge, but even if my supposition of Italian influence be correct, the fact of such an interest in eye-glasses remains none the less noteworthy. The practical man, by whom Daza de Valdes was informed, must have had quite a remarkable knowledge: anisometropia, hypermetropia between 4 and 5 D, protecting glasses in meniscus form, impression of coldness in touching pebble lenses, collective lenses with sharp rims, and other things were known to him. As he mentions spectacles "attachées avec des agraphes aux oreilles," there is a possibility of his having recommended ear-spectacles as early as 1623. A notice by P. Pansier (40) is in good accordance, when he says that he saw in the Peiresc collection (time about 1629) the drawing of an old Spaniard wearing spectacles of such a kind. I myself have of course not seen these objects in the Peiresc collection in Paris, but I mention them here, as perhaps someone in my audience may have occasion to look up this source of Pansier's and report more fully about it.

Fig. 7. Medal showing the Marquis d'Astorga with nose-spectacles; taken from Ref. (41).

As places with spectacle manufacture Daza de Valdes mentions Madrid, Lisbon and Seville, especially the last, where an export trade of spectacles with the colonies was established. He does not speak of Barcelona.

That the spectacles were valued even in the highest Spanish circles is corroborated by a report (15) reprinted in J. Rouyer's book. This report was written in 1645 by Mme d'Aulnoy, a lady of the French court, about her impressions at the Spanish court. As at that time spectacles used not to be worn in good Parisian society, she was the more struck by the difference in Spain. She especially mentioned spectacles "attachées aux oreilles," but we do not know whether they were ear- or thread-spectacles. Opticians ought to follow up traces of this kind; in consequence of the general impoverishment such investigations are hardly possible in the Germany of to-day, but in countries where the conditions for scientific work are more favourable this interesting time should be studied somewhat more. The Spanish predilection for spectacles seems to have subsisted some time: A. v. Pflugk has shown (41) that such a high dignitary as the Viceroy of Naples (A. Alvarez, Marquis d'Astorga, 1672–5) used to wear nose-spectacles in public; he is represented in a picture in this way, and there is also a medal (Fig. 7) showing him with his nose-spectacles.

In the 18th century, however, this custom seems to have gradually succumbed before the French usage of concealing the ametropic state of the eyes as much as possible. When ear-spectacles appeared again between 1702 and 1714, they seem to have been of English production. We are still uncertain as to the time when nose-spectacles (the pince-nez of the present day) were re-introduced; I have been unable to trace them previous to 1846.

V. *Further growth and gradual decline of the South German spectacle factories in the 17th and 18th centuries*

There is hardly any doubt that during the first peaceful eighteen years of the 17th century the general manufacture of spectacles in South Germany was in the same state as already described. About that time the Nürnberg craftsmen introduced a new order for the master pieces, built up on Regensburg influences, and for more than 100 years these master pieces were always made in the same manner quite apart from the ordinary work of the day. Such an important invention as the Dutch telescope does not seem to have extended its influence to the spectacle makers in South Germany, probably because at that time the demand could not call for great numbers of telescopes. That the means for grinding and polishing were not improved, we may gather from an eyewitness. H. Sirturus tells us that at Regensburg he saw two boys grinding at the same stationary bowl with both hands. In this way four weak collective lenses were finished at once. But such deterioration showed itself to the eyes of this observer in other places of spectacle manufacture as well: he mentions having seen at Rome and Venice the use of such sharp polishing means as *aqua fortis* in order to save time.

The Thirty Years' War, under which Nürnberg as well as Regensburg suffered so much, cannot but have lowered the standard of execution, and we must expect a comparatively low state of the spectacle manufacture in these places during the second part of the 17th century. The free guild of Regensburg seems to have observed the old order as much as possible, and a lucky chance has preserved the testimonial (42) given in 1686 to an apprentice after having served his years in glass grinding (Fig. 8). It is probable—though strict evidence is wanting—that the Regensburg craft was then more given to the manufacture of telescopes, the spectacle manufacture not proving sufficiently remunerative in consequence of the Nürnberg competition.

The conditions in the Free Town of Nürnberg were quite different; the trade manufacture was further developed, but only in the direction of cheapness and number of the goods turned out. As the times were bad, the masters began to lessen the status of the journeymen and to develop small factories instead of the old handwork with one or two journeymen. Their situation became more precarious; the number of years for serving as apprentices and journeymen before being fit for the last examination was lengthened in 1647 to ten, in 1672 to twelve years. Restrictions with regard to taking in apprentices are reported for the years 1655, 1672 and 1675.

Nevertheless this hard time was not totally devoid of progress; its direction,

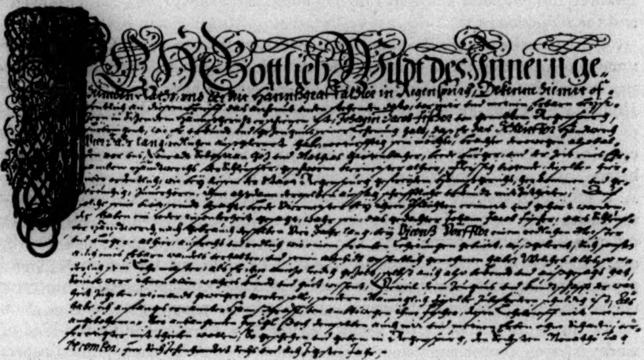


Fig. 8. Testimonial (Lehrbrief) given to an apprentice in 1686 for having served his time; taken from Ref. (42).

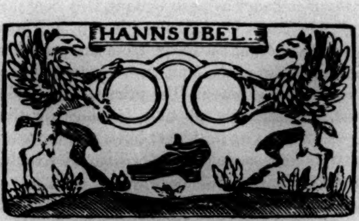


Fig. 9. Woodcut.

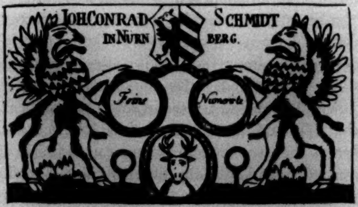


Fig. 10. Copper engraving.

Woodcut and copper engraving for cards glued on little boxes containing spectacles; taken from Ref. (19).

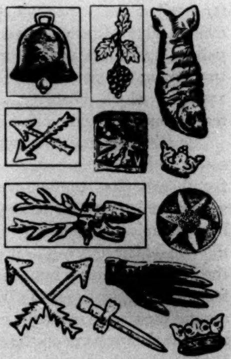


Fig. 11. A collection of master signs, mostly of Nürnberg origin; taken from Ref. (19).

however, did not point to a higher quality but almost alone to the quantity of goods and the reduction of the price.

We have already (in Section II) drawn attention to some German metal-mounted spectacles made towards the end of the 16th century; according to pictures of that period this kind of mounting seems to have been much in use in Holland. Spectacles in such mountings appear in the decrees of the High Council of 1675 in Nürnberg at the same price as spectacles in leather or horn: from this equality of price we may conclude that they had been put on the market some time before, and the difficulties of the manufacture had been already overcome. A. v. Pflugk's investigations (19) have shown that the first Nürnberg metal-mounted spectacles were rather clumsy, the mounting being hammered by hand, and the difficulties of putting name, sign, and town on the mounting could not then be overcome. For this reason, probably, the craft began to give these data in printed paper, partly on cards glued on little boxes (eine Lade) containing six, eight, ten or twelve pairs of spectacles, and partly on longer strips for wrapping up the spectacles. In the earlier time, about 1640, woodcuts (Fig. 9) were employed for this kind of work; later on copper engravings (Fig. 10) were preferred. These printed papers were retained, even when the industry had overcome the difficulty and was able to provide the metal mounting with the necessary details. The boxes before mentioned were an innovation that had its bearing on the trade customs as well. Whereas formerly the dozen was the unit for the merchant buying his goods, it is now the box (die Lade), and at first the number of boxes for a Thaler (then 3*s.* 4*d.*) was given, later on the price in Thalers for 100 boxes; so we see from the price list for retailers the way in which the single masters of the craft were deposed by the owners of small factories working with division of labour. The price for the single pair of spectacles was at first the same as formerly, about 3 farthings for the tradesman; it went down about the year 1741 to 2½ farthings; but about the year 1773, for which reliable information (43) is forthcoming, renowned factories could realize something like 4 farthings for the ordinary pair.

So trifling a price was the effect of the development of the metal mounting; it seems to have been brought about in sixty years or so. We have pointed to the fact that the first common metal mountings were hammered by hand; we hear that some time later (19) the flattening of the brass thread and its grooving was effected by mechanical means (Plättmühle) worked by water power, and we know that in the end—after 1730—the pressing part was so improved that it not only grooved the flattened thread but (as Namen- or Musierwelle) also imprinted on it the factory name, sign (see Fig. 11) and town. The thread treated in this way was bent around the glasses in such a manner that in the middle a part remained free in order to effect the pressure on the nose, whereas the two mountings proper were finished by fastening the loose ends of the grooved thread with the finest binding thread. In this way the unknown inventor or inventors had brought the mounting to a very simple and easily-made form, that could be sold at a very low price at home and abroad to the masses, who did not attach great value to the exterior. Doubtless the solidity and adaptability, as developed by the Regensburg masters in the different forms of their horn mountings for nose-spectacles, were lost. These qualities could not be retained with such a striving after the largest numbers. And in the time of such development the Nürnberg craft retained the old master pieces according to the necessities of 1510 or 1580, not realizing that the fundamentally altered times were bringing forward important questions enough with regard to the cheap spectacles! Nevertheless money was still to be made in this way, as we may conclude from the important competition in the neighbouring town of Fürth. In this place—it belonged to three different political powers—not even the rickety and rotten barriers preserved in Nürnberg against underselling competition were in existence, and we cannot wonder that the spectacle prices of the Fürth industry (introduced there about the year 1710 by Günert brothers and J. E. May) remained even below (44) those of Nürnberg. We have found evidences enough in the second half of the 18th century to be sure of our statement. The old primitive and unwholesome way of grinding and polishing was retained and the methods of putting out the greatest number of indifferent glasses were developed with diabolical ingenuity. We find it asserted in letters and descriptions of that time that no other place could compete with Nürnberg-Fürth as regards the production of cheap spectacles for the masses. Once only the experiment was made according to a premeditated plan to introduce this kind of manufacture (45) to the East of Germany, to Frankfurt a. Oder, where Frederick the Great tried to found a factory for cheap spectacles. The experiment absolutely failed, probably because this kind of work could only be effected by a population used to it from childhood.

Such cheap spectacles are well known to us; the different collections contain such pieces, preserved in rather great numbers. Whoever wishes to learn more details on these questions must be referred to R. Greeff and A. v. Pflugk. The outward appearance of this kind of spectacles was not bad: the brass thread was silvered (leonischer Draht) and contrasted not disagreeably with the glasses having a green tinge. In daily use, however, the thin silvering soon disappeared.

A great quantity of such spectacles was sold at home and abroad without difficulty, as they were extremely cheap. From the reliable reports of the Prussian counsellor Trummer (45) we know that a pair of nose-spectacles was sold in 1773 by the pedlars at about 4*d.*; it was impossible for a manufacturing optician to furnish his cheapest goods at such a low price. I remember having seen the value of the cheapest nose-spectacles in London fixed at that time at 1 shilling, or about three times the money. Two different points may be mentioned as evidences of the fact that the Nürnberg-Fürth industry exported their goods to England as well.

The first is a direct evidence: in an old stone coffin (46) opened about 1828 there was found a pair of nose-spectacles bearing on the metal rims the inscription: Jo. Erhardt May Seel. Erb. Peter Conrad Weigel. We know from independent sources that P. C. Weigel was son-in-law and successor to J. E. May, the founder of the Fürth spectacle industry, and as it seems certain that the rims were pressed on the improved apparatus (Namenwelle), we must date this pair at a year later than 1730.

The second example we take from Goldsmith's *Vicar of Wakefield*, where

Moses gives away the colt for a gross of silver (!) spectacles. I should like to suppose that here South German spectacles were used in order to cheat the inexperienced boy, as the spectacles were not handed over by an optician in his shop but by vagabonds in the turmoil of a fair. It is quite likely that Goldsmith had heard of similar cases, and the whole description, with the copper wire thinly silvered, agrees wonderfully well with the knowledge we have of the outward appearance of those cheap nose-spectacles. I may add another instance still: when McAllister (47) in 1783 opened his store in Philadelphia with "a bushel basket full of spectacles," we must conclude that they were the cheapest factory-ware, as no optician would speak in so derogatory a manner of his laboriously finished goods. May not these have been Nürnberg-Fürth goods as well?

Direct accounts concerning the export trade of the factories are not very numerous; I should even think that some part of this trade was done by middlemen without knowledge of these factories. As far as I have found any information, May's and his successors' spectacles were exported to England, Austria and Italy; other Fürth factories sent their goods to Scandinavia and Finland. This fact has been corroborated by the historical studies published in 1914 by P. Wirzenius (48), who generally found old spectacles of German (i.e. Nürnberg-Fürth) origin in northern collections. Concluding these evidences of the Fürth trade, I may cite a sentence of later date, that possibly contains correct information: "as the lenses were good as well as cheap, large quantities were exported to England, where the glasses were taken from their simple mountings and mounted anew."

On the whole, the South German spectacle factories aimed too much at cheapness. They have certainly helped the masses of many European countries to cheap eye-glasses, and in so far we may mention them with this qualified approval. But as they were decidedly against any alteration that might interfere with the cheapest production, the quality of their goods could not nearly be compared with those brought out by conscientious opticians. It was to be expected that, as soon as a factory was established in Germany with new and advanced methods of grinding and polishing, the Nürnberg-Fürth factories would suffer considerable loss; and indeed this industry could not hold its own in the face of the competition of better governed factories in the 19th century.

VI. *The growth of the spectacle grinding optician*

The beginning of the 17th century pretty well coincides with that of an optical epoch, that is to say, with the invention of the Dutch telescope patented in 1608. It cannot be our object here to describe the general impression made on the whole civilized world by the new invention, which from its beginning was extensively used for military purposes; the Italians especially seem to have been interested, whereas at present we do not know anything of its development in Holland. In 1618 busy Sirturus tells of comparatively old experiments with the telescope made by him and his friends, and the reliable Count C. A. Manzini gives us interesting details (39) regarding the steps taken in Venice in connection with the regular construction of Dutch telescopes long before 1660 and the trade in such instruments. One of the mirror grinding masters in Venice taught him how to form and polish lenses, and he pays him his tribute of thanks in a manner honourable to both concerned.

Evidently the new problems gave, so to speak, fresh life to the lens grinding profession and, luckily enough, there were some Italian scientists then willing to direct their energies to the new instrument; we shall here only point to G. Galilei, H. Sirturus and C. A. Manzini. Very soon the inmates of different monasteries were interested in the new invention, and we cannot wonder that the most learned order, the *Societas Jesu*, took their share in this development. It is only necessary to mention the name of C. Scheiner, a man equally important as optician, physiologist and astronomer, in order to show that the Jesuits then possessed scientific members of a very elevated rank indeed. The methods for grinding and polishing—as the books of H. Sirturus, C. A. Manzini, Z. Traber, J. Zahn, Chérubin d'Orléans amongst others show—were developed scientifically and the results were communicated in a very liberal manner, as no pecuniary interests were in question. As these books were written in Latin, then the general medium for scientific communication, the whole discussion was held, so to speak, in a higher sphere and far removed from the daily cares of the nether world of artisans and mechanics. I should especially advise those of my hearers who are able to understand the Latin of the 17th century to read the programme (49) of the Jesuit Balthasar Conrad (1599–1660). Personally I know of few opticians who could have conceived the plan of an optical book with the same disinterestedness and with the same purely scientific aim.

But to return to the opticians of the 17th century! As such optically interested monks ground lenses and adapted them—preferably to clerical patients—they kept an observant eye on the people, whose sight they improved, and they wrote down their clever observations. J. Zahn wrote such a treatise in 1686 in a very successful way, and I do not think that any of the spectacle books in the 18th century were markedly superior to Zahn's chapter on eye-glasses. I willingly agree that the books of C. Hertel in 1716, of M. Thomin in 1746, and of G. Adams in 1786—in order to mention a remarkable optician of each of the three nations in question—gave more details occasionally, but I do not think that they were of a decidedly superior conception to that of this old monk.

These spectacle adapting monks were soon replaced by the group of artisans whom to-day we call opticians; it is not impossible that they learned a good deal from these clerics, but unfortunately the state of optical history does not allow of giving evidence for this.

My hearers will doubtless be interested in my bringing together some information as to the designation "optician" which is universally used nowadays. It was not so formerly, as, for instance, J. Kepler, in the title of his grand book containing the foundations of modern optical knowledge, uses the term "opticus" for a man versed in the fabric of the eye in the sense of physiologists who specially studied the parts of the eye and their use. By a happy chance, and with the valuable help rendered by my friend Dr Seitz, I was able to buy an old copper engraving (Fig. 12) of 1635 for the Zeiss collection. It shows the bust of a man otherwise unknown, C. Müller of Berlin, who was *Notarius Publicus et Electoris Brandenburgici Opticus* at that place. This man, who had certainly received a university education as a law student, may have had a hobby for optical experiments and curiosities. Parading it before the Berlin court of that time he obtained the court title of "Opticus," as we see from the engraving. It is decidedly coupled with his scientific character and has no relation to any optical trade. Soon afterwards, however, things were changed: a Capucine friar (50) of a higher rank, Antonius Maria Schyrlaeus de Rheita, tells us in 1645 of an artisan G. Mattmüller, who was Sacr. Caes. Maj. Opticus, and of another, J. Wisel, whom he describes as an opticus in Augsburg.

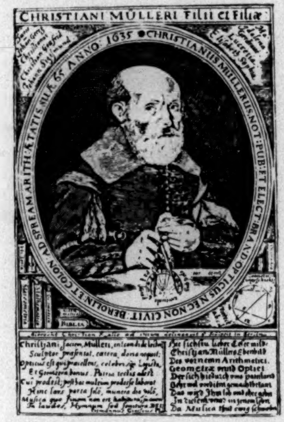
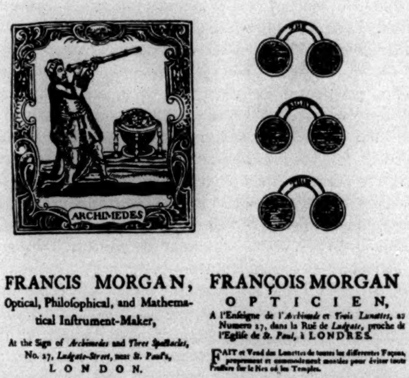

CHRISTIANI MÜLLERI FILII ET FILIÆ
ANNO: 1635 • CHRISTIANUS MÜLLERUS NOT: PUB: ET ELECT: BRAND: OPTICUS NEC NON CIVIT: BEROLIN: ET COLON: AD SPREAM ARITH: ÆTATIS SUÆ 65
BIBLIA

Fig. 12. Copper engraving of 1635, showing the expression "opticus" as a scientific title.

We may therefore take for granted that the use of the word opticus for a certain craftsman was quite an ordinary thing for scientific men writing Latin in the middle of the 17th century, and it seems that this was effected at least for some parts of the German territory by the intermediate step of a court designation. In 1710 the Coburg schoolmaster J. M. Conradi uses (51) the word Opticus in a German booklet for a craftsman as a matter of fact not requiring any explanation. With regard to the linguistic use of the French term "opticien" in the 18th century I have not sufficient knowledge to be able to treat it at greater length before you. It is, however, possible that it was in general use sooner than the corresponding word "optician" in English. Taking, for instance, F. Morgan's bilinguistic handbill (13) as reproduced in the *Optician* some years ago (Fig. 13), we notice that Morgan described himself in the English half as an Optical, Philosophical and Mathematical Instrument-maker, whereas in the French half he uses the simple expression opticien. As there is no date given to this handbill, we must try to date it by deduction and I hope to do so in this way: In the passage before the last but one we read "Octants de Mons. Hadley." We must therefore conclude that the instrument-maker Hadley was then alive, and his London colleague Morgan was certainly able to know that. As far as I could ascertain, John Hadley brought out his quadrant in the year 1731 and died in February, 1744. We have therefore for the date of this handbill an uncertainty of thirteen years, but we may suppose that a somewhat longer time was necessary before other instrument-makers advertised the invention of one of their competitors, so that we come somewhat nearer to 1744. In passing, I may observe that we can place this F. Morgan in the company of the nine old opticians of note, whom R. B. Prosser enumerated (52) some years ago in discussing an historical document of optical value. There we find Morgan residing in Cary Street, whereas in the handbill he gives his address as 27, Ludgate Street. We will, however, return to the designation "optician." It was perhaps not in general use even towards the end of the 18th century, as W. C. Wells, a London physician and scientist of great insight (53), uses this term in 1792 almost in the same sense as Kepler 188 years before, whereas he designates the spectacle maker as "artist." It may, therefore, be advisable to look up the old designations for artisans of this kind in order to ascertain the date when the term optician comes into everyday use in the English language.


ARCHIMEDES

FRANCIS MORGAN,
Optical, Philoſophical, and Mathematical Inſtrument-Maker,
At the Sign of *Archimedes* and *Three Spectacles*,
No. 27, *Ludgate-Street*, near *St. Paul's*,
LONDON.

FRANÇOIS MORGAN
OPTICIEN,
A l'Enſeigne de l'*Archimede et Trois Lunettes*, au Numero 27, dans la Ruë de *Ludgate*, proche de l'Egliſe de *St. Paul*, à LONDRES.

FAIT et Vend des Lunettes de toutes les differentes Façons, proprement et commodement montées pour éviter toute Froiſſure ſur le Nez où les Temples.

Fig. 13. Morgan's handbill of about 1740, showing spectacles of very old form; taken from Ref. (13). Compare the spectacles of 1640 shown in Fig. 9.

After this linguistic digression we may remark that about the year 1680 these craftsmen (54) seem to have taken up the regular production of small Dutch telescopes under the name of "perspectives." The new designation perspective-makers is then to be found in the South German towns. In the 18th century and especially in South Germany it becomes quite a regular custom for artisans of higher repute to call themselves opticians and perspective makers. We may understand the reason from a custom then prevalent in the higher circles. In Mme Heymann's book (55) too we find in the 18th century a great number of small perspectives, mostly with tasteful decoration, French etiquette forbidding the wearing of spectacles in good society; one of the precarious helps allowed to ametropic people was the stealthy use of a small perspective hidden in the wearer's hand. It is possible that this custom was not so prevalent in England, whereas it seems to have ruled quite despotically in good Continental society.

With regard to the English spectacle industry, we have already pointed out in the first part of this lecture that it must have existed, although we do not know many particulars besides the quadrilateral forms of the glasses and their price. From the Charter of 1629 we see (56) that at that time the importation of spectacles was quite an ordinary thing, and it was the privilege of the guild to judge (and to condemn) not only home products but imported goods as well. The severity of the judgment, however, seems to have abated considerably during the 18th century. The guild's charter was signed in 1629 by Charles I. The guild must have contained quite a considerable multitude of fellows, as there were then to be elected one Master, two Wardens, eight Assistants, and one Clerk. The by-laws are known to me only in so far as L. Laurance's report (57) of them goes. We here find restrictions regarding the number of journeymen as well as even regarding the quantity of the ready-made goods. Purchased glass had to be distributed among all the fellows of the guild, another custom of very great importance. There seems to have been some change in the year 1739, testified by the alteration of the Company's Coat of Arms. W. Wolley gave some description (58) of it, and from that time optical instrument-makers were included. I am not in a position to say whether these could only be elected as new members, or whether London's spectacle makers in general developed themselves into opticians in the above wider sense. About the beginning of the 18th century we find that form of spectacles in London which to-day bears this name by preference, that is to say ear-spectacles. M. W. Dunscombe has shown (59) such pieces, formerly belonging to his grand collection. He dated them between 1702 and 1714, and an authority like the late E. Pergens adopted (60) his opinion. I can point to a comparatively early mention of such spectacles in R. Smith's *Optics* of 1738, but I am sure still earlier references will be found, if more attention is directed to such places. We must, however, wait for the results of the investigation on Spanish spectacle inventions, in order to decide whether the London ear-spectacles were a real invention or a re-invention only. I should think that these spectacles were worn in public as well, although I cannot prove it. In any case London opticians improved such spectacle mountings with an eye to easy and comfortable wear, and the pair of spectacles with deep negative glasses dug from the ground at Bath and being worn about 1750 seems to allow of my supposition. By the way, it would be interesting to know whether there was any public discussion about the time of the new custom of wearing spectacles in society. From the corresponding utterance of opinions to be found in German books and newspapers I was able to learn diverse details, even the great Goethe contributing towards my knowledge and curiously enough declaring himself against the continued wearing of spectacles.

Returning to the old opticians—whether they were designated by this name or not—it is quite remarkable how many different instruments they sold. J. M. Dobler of Berlin (61) in 1719, F. Morgan of London (13) before 1744, M. Thomin of Paris (62) in 1746, and J. F. Meyen of Dresden (63) in 1747 have left lists of their wares, and it is in every case quite a confusing variety of objects. In Dobler's case the influence of Zahn and Sturm is not to be denied: he at least depends on scientific workers.

If we now try to form a more exact picture of these old opticians, we shall restrict ourselves mostly to London masters. This will be not only more interesting for my audience but also more reliable, as my knowledge of these old craftsmen is decidedly the most developed for London. As to the Parisian optical masters I have a more intimate knowledge of M. Thomin only, and in Germany these men were seriously handicapped by the want of a great capital or metropolis and also by the fact of so many retail dealers selling spectacles bought in large quantities from the Nürnberg-Fürth factories. It was quite correct that the exact optician of the 18th century was against the antiquated and imperfect methods of grinding and polishing that were used in the old factories. But, unfortunately, the opticians seem to have undervalued other and more useful experience coming from that quarter. In this way the graduation according to power was lost, although it had been in use with the Venetians, as I think, and certainly with the Spaniards. H. Sirturus' bad example was universally followed, when he used a graduation according to the length of the radius of the grinding tool, and I know of no optician of the 18th century from Leutmann to Ramsden who used any other than this unpractical scale. Much labour was to be lost by scientific oculists during the sixties of the 19th century, before in 1873 the ground was ready for the international graduation in dioptres, although a graduation on a similar basis had apparently been in use before 1585. To give another instance of a regression, the knowledge of the fact that plano-convex and plano-concave lenses in their proper positions were preferable to lenses with equal radii was widely spread at the end of the 16th century, as I tried to show before; but such a well-instructed optician as M. Thomin denied this as late as 1746. In this connection I should like to point out the stubborn confidence shown sixty years later by W. Jones (64) in the fight with his great adversary W. H. Wollaston: we must suppose that the community did not escape the danger of being satisfied with their limited store of mathematical knowledge. At this time there are undoubtedly some pleasing exceptions, and I wish to direct your attention to J. G. Leutmann (1667–1736), at first a parson (65) in Dabrun near Wittenberg and later on technical Professor in St Petersburg, who as early as 1719 pointed out the advantage of the meniscus lens for negative and for positive powers. Although he did not give such an elaborate explanation as Wollaston did eighty-four years later, his lenses appear to have been rather more deeply curved than the glasses made in 1804 by Dollond under Wollaston's patent. But even the limited success of the periscopic glasses was denied to Leutmann; the opticians of his time did not act upon his advice, although his little book of the year 1719 met with a most remarkable sale, its fourth edition being printed as early as 1728.

As in the beginning of the 17th century the Venetian opticians improved their methods of grinding and polishing by making Dutch telescopes, so the London opticians derived 150 years later a remarkable advantage over their Continental colleagues by following Dollond's example and bringing achromatic telescope objectives on the market. The grinding and polishing of several surfaces forming a part of one and the same sphere was within the reach of every craftsman in

London, as testified in 1813 by Wollaston. I should think that this exact and useful method had been developed or spread in connection with the refinement necessary for the new objectives. I have found in one of the German mercantile dictionaries, printed towards the beginning of the 19th century, a statement with regard to the greater accuracy of English workmanship.

In the second half of the 18th century the London optical craft must have prospered exceedingly well. E. K. Spiegelhalter gave (66) a part of W. Jones' (of Wollaston memory) list, from which we see that in 1799 the best double-jointed standard gold spectacles (gold case included) were sold at 16 guineas, and in 1813 the same optician still offered a pair at 12 guineas. We can quite understand that the prices of ordinary spectacles at this time were also comparatively high. As I have no prices of these years at hand, I shall cite prices of a time not far advanced: in April, 1804, W. Jones charged 3*s*. 6*d*. for ordinary spectacles with biconvex lenses of + 10 D, and W. Kitchiner in 1824 gives (67) on p. 10 the price of 1*s*. 6*d*. (probably with weaker lenses), and on p. 120 after Samuel Pierce (when?) 2*s*. In any case we may safely assume that towards the end of the 18th century people of restricted means were tempted to buy foreign (South German) spectacles, although they were not nearly so well finished as spectacles from reputed London houses. As to the amount of spectacles imported I have no detailed knowledge and do not think it probable that such will be forthcoming; details of these old times have been lost to such an extent that these particulars will also have vanished.

Returning once more to the London opticians, we are now able to obtain from the Patent Office's publications some knowledge as to their principal aims. It was not so in those times when patent specifications were difficult (68) to obtain. You will here certainly remember Dickens' biting description of the Circumlocution Office in *Little Dorrit*. It is only after the change effected between 1852 and 1859 that the old English patents became easily accessible. Taking advantage of these descriptions, and using at the same time other printed sources as well, we may say that J. Ayscough in 1750–2 directed his attention (69) to the glass material for spectacles and also to their joints, in 1756 B. Martin to the centering and the diminution (70) of the working diameter (visual spectacles), in 1783 A. Smith to spectacles (71) with double glasses, which idea was further developed in 1797 by J. Richardson working (72) in the direction of mere protecting and coloured glasses. In 1783 W. Storer advertised (73) quite small (syllepsis-) glasses, also very extensively imitated at that time, in 1785 H. Dixon combined glasses (74), a kind of telescopic spectacles, in 1789 G. Adams folding eye-glasses (75) for binocular vision, in 1797 D. Adams front spectacles (76), sometimes erroneously ascribed to John Herschel. In 1799 W. Cary communicated to Thomas Young the observation on the means for correcting astigmatism of the eye (77). I am afraid that other innovations have escaped my researches, but a certain part of them, I am sorry to say, will be lost for ever. Some of these inventions were not really new, if we apply the sharp enquiry used by a modern patent office, but they all gave to the opticians of that time a considerable self-respect that—well grounded on the whole

—was sometimes apt (for instance, in the discussion between Wollaston and W. Jones) to overreach its object.

With all their knowledge, however, these craftsmen were not easily impressed, and we have no reason to suppose that opticians or oculists of that time were ready to make use of Young's great discovery, although the same means were at their disposal as those with which J. I. Hawkins in 1826 made his splendid researches on the astigmatism of his own eyes. We shall not follow up the history of regular spectacle correction for astigmatic eyes, as this entirely belongs to the second half of the 19th century: so far ahead was Thomas Young with regard to his contemporaries!

One question only may be put to London opticians concerning an optical invention of the 18th century: what is the date of the first bifocal spectacles? You will allow me to state some exact data.

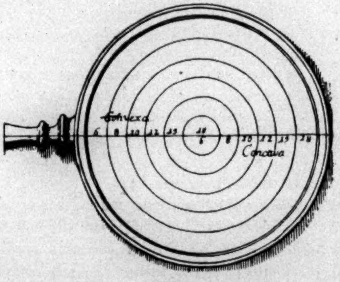


Fig. 14. Split multifocal testing lens of 1716, showing the framing of "divided" glasses; taken from Ref. (78).

The combination of two divided glasses by means of the mounting was known to C. Hertel in 1716, as shown (78) by Fig. 14. In 1784–5 Benjamin Franklin described (79) his spectacles made in such a way. As far as I know, they were first accredited to him in 1804 by W. Jones, then in 1806 by J. G. A. Chevallier (80). Later on this knowledge seems to have been forgotten in London, as W. Kitchiner in 1824—and he was certainly well informed in spectacle questions—ascribes them to Samuel Pierce. In our time an authority like W. M. Dunscombe gives the year 1760 as the date, and that is certainly possible, as Franklin was then in his fifty-fourth year and staying in London as well. His description of 1784–5, therefore, may have been of an invention conceived at a much earlier time. Even a recent American source (81) gives 1760 for Franklin's spectacles, and it is not impossible that Pierce had made them long before the date of the first publication in 1784–5. In such a case they were—although not published—in public use, and some credit for the invention ought to be given to Pierce as well. Can anybody furnish new knowledge on this topic?

Ladies and Gentlemen, I have come to the end of my lecture and must ask your pardon for all the mistakes and unwonted terms that remain in my text in spite of the continual grinding and polishing exertions kindly undertaken by my wife.

I must expect that some of my hypotheses will be amended, modified or altered by future study; nevertheless as working helps they will be, I hope, of some service. I have taken the utmost care to give you all I possess in the way of sources at this time in connection with our subject, and I shall close with the hope that this lecture will help in stimulating historical spectacle studies and throwing thereby on different shadowy periods the light of historical discoveries.

Sources and References

The two abbreviations often used in the following pages refer to two of my recent books:

Bin. Instr. = *Die binokularen Instrumente*. 1920.
Br. a. opt. Instr. = *Die Brille als optisches Instrument*. 1921.

Both published by J. Springer, Berlin.

(1) Title under G. Govi (*2*) in Bin. Instr. 284. See p. 167. [42][*]

(2) Title under F. Risner (*1*) in Bin. Instr. 294. [42]

(3) Bridges, J. H. The "opus majus" of Roger Bacon. 2 vols. (Oxford: Clarendon Press, 1897.) See vol. 2, pp. 152–8; Combach, J. Rogerii Bacconis Angli, viri eminentissimi, Perspectiva. In Qua, Quae ab aliis fuse traduntur, nervose & ita pertractantur, ut omnium intellectui facile pateant. Nunc primum in lucem edita. Pp. (6) + 189, 8vo. (Francofurti: Typis W. Richteri, sumptibus A. Hummij, 1614.) [42]

(4) The verse has been reprinted by J. Hirschberg. Geschichte der Augenheilkunde im Mittelalter und in der Neuzeit. Pp. xx + 546, large 8vo; 69 Figs. and 8 Plates. (Leipzig: W. Engelmann, 1908.) See p. 272; also M. v. Rohr (*45*) in Br. a. opt. Instr. 244. See p. 12. [42]

(5) Greeff, R. Der Beril des mittelhochdeutschen Dichters Albrecht (1270). *Z. f. ophth. Opt.* 11 (1923) 66–7. [42]

(6) Greeff, R. Der vergrössernde Krystall Konrads von Würzburg (*c.* 1275). *Ibid.* 11 (1923) 98–101. [42]

(7) Albertotti, G. Lettera intorno alla invenzione degli occhiali scritta da — all' onorev.mo. Senatore Isidoro del Lungo. *Ann. di Ottalm. e clin. ocul.* 50 (1922) 85–104; 6 Figs. and 1 Plate. [42]

(8) Greeff, R. Eine venetianische Brillenmacherordnung aus den Jahren 1284–1317. *Deut. Opt. Wochschr.* 8 (1922) 600–2, 620–3, 639–42. [43]

(9) Greeff, R. Eine zweite venetianische Brillenmacherordnung vom Jahre 1319–1330 (von anno 1318 bis 1330). *Ibid.* 8 (1922) 802, 824–7, 852–4, 870–4. [43]

(10) v. Humboldt, A. *Cosmos*, Stuttgart u. Tübingen, 2 (1847) 508. [43]

(11) Greeff, R. Nikolaus von Cusas Buch "De Beryllo." *Z. f. ophth. Opt.* 5 (1917) 42–4. [43]

[*] The numbers in square brackets refer to the pages of the text where the sources and references are mentioned.

(12) Eygentliche Beſchreibung Aller Stände auff Erden / Hoher vnd Nidriger / Geiſtlicher vnd Weltlicher / Aller Künſten / Handwercken vnd Händeln / &c. vom gröſten biß zum kleineſten / Auch von jrem Vrſprung / Erfindung vnd gebreuchen. Durch den weitberümpten Hans Sachſen Gantz fleißig beſchrieben / vnd in Teutſche Reimen gefaſſet / Sehr nutzbarlich vnd luſtig zu leſen / vnd auch mit künſtreichen Figuren / deren gleichen zuvor niemands geſehen / allen Ständen ſo in dieſem Buch begriffen / zu ehren vnd wolgefallen / Allen Künſtlern aber / als Malern / Goldſchmieden / &c. zu ſonderlichem dienſt in Druck verfertigt. Mit Röm. Keyſ. Maieſt. Freyheit. Gedruckt zu Franckfurt am Mayn. M.D.LXVIII. [44, 48, 49]

(13) An optician's sign. *Optician*, 8 (1894–5) 297 (1 Fig.). [44, 60, 61, 62]

(14) v. PFLUGK, A. Der biblische Moses mit der Brille. Ein Nachtrag zu dem gleichnamigen Aufsatz in Nr. 43/44 vom 26. Oktober 1920. *Deut. Opt. Wochschr.* 5 (1920) 416–7. [44]

(15) Title under J. ROUYER in Br. a. opt. Instr. 244. See p. 102. [44, 53] In the latter case [53] see also under [La Mothe, M. C., Comtesse d'Aulnoy]. Relation du voyage d'Espagne, Tome premier, Seconde Édition, pp. 186, 12mo; Tome second, pp. 176; Tome troisième, pp. 228. (A la Haye: Chez Henry van Bulderen, MDCXCII.) See Tome second, pp. 139–42.

(16) v. PFLUGK, A. Beiträge zur Geschichte der Augenheilkunde in Sachsen. Nach einem Vortrag im kgl. Sächsischen Altertumsverein. Pp. 22, 8vo; 4 Figs. (Dresden: C. Heinrich, 1913.) [44, 51]

(17) v. ROHR, M. Ueber Brillenpreise aus ältester Zeit. *Centr. Ztg. f. Opt. u. Mech.* 40 (1919) 209–11. [44, 45]

(18) Title under O. HALLAUER (*2*) in Br. a. opt. Instr. 233. [44]

(19) v. PFLUGK, A. Die Meisterzeichen der Nürnberger Brillenmacher. *Arch. f. Aughlkde.* 91 (1922) 341–60 (22 Figs.). [44, 49, 55, 56]

(20) MÜLLER, C. Ueber Brillenpreise im Mittelalter. *Centr. Ztg. f. Opt. u. Mech.* 39 (1918) 18–19. [45]

(21) v. PFLUGK, A. Noch eine alte deutsche Brillenmacherordnung. *Z. f. ophth. Opt.* 11 (1923) 33–40. [45]

(22) MÜLLER, C. Nürnberger Brillenmacher-Ordnungen und -Ratserlasse. *Deut. Opt. Wochschr.* 7 (1921) 874–7, 895–7, 915–7. [46, 49]

(23) v. ROHR, M. Die Nürnberger Brillenherstellung. Ein Versuch einer zusammenfassenden Darstellung. *Centr. Ztg. f. Opt. u. Mech.* 43 (1922) 185–7, 206–8, 225–7. [46]

(24) NEUBURGER, S. Die Regensburger Brillenmacherordnung. *Janus*, 9 (1904) 94–102; MÜLLER, C. Die Regensburger Brillenmacherordnung. *Deut. Opt. Wochschr.* 7 (1921) 720–6 (6 Figs.). [46, 47]

(25) v. ROHR, M. Optische Bemerkungen zur Regensburger Brillenmacherordnung um 1600. *Z. f. ophth. Opt.* 8 (1920) 76–85, 97–103 (3 Figs.). [46, 48, 49, 50]

(26) R. D. FRANCISCI MAUROLYCI abbatis Messaniensis Mathematici celeberrimi Theoremata de lumine, et umbra, ad perspectivam, & radiorum incidentiam facientia.

Diaphanorum partes seu libri tres: In quorum primo de perspicuis corporibus: in secundo de Iride: in tertio de organi visualis structura, & conspiciliorum formis, agitur.

Problemata ad perspectivam & Iridem pertinentia.

Hic accesserunt Christophori Clauij e Societate Jesu notae, asteriscis inter authoris demonstrationes distinctae. Adscriptis ad marginem fundamentis, quibus omnia innituntur. Pp. (3) + 94, 4to.

(Lugduni. Apud Bartholomeum Vincentium, M.DCXVII.) Cum Privilegio. [46]

(27) SUTCLIFFE, R. A plea for lesser intervals in the dioptric scale. *Optician*, 10 (1895–6) 216. [46]

(28) DÜRER, ALBRECHT. Tagebuch der Reise in die Niederlande. Pp. 95, 8vo; 8 Plates. (Leipzig: Inselverlag, no date given.) Nr. 150, p. 41. [46]

(29) v. ROHR, M. See *Centr. Ztg. f. Opt. u. Mech.* 43 (1922) 67–8. [48]

(30) Title under A. v. PFLUGK und M. v. ROHR (*38*) in Br. a. opt. Instr. 240. [48, 53]

(31) v. Rohr, M. Ein Versuch zur Ermittelung der optischen Kenntnisse der Brillenhersteller um das Jahr 1600. *Z. f. ophth. Opt.* 10 (1922) 1–8, 33–7 (3 Figs.). [48, 53]

(32) Der Frankfurter Markt oder die Frankfurter Messe von Henricus Stephanus (Henry Estienne). Im Auftrage der Städtischen Historischen Kommission in deutscher Übersetzung herausgegeben von Dr Julius Ziehen. Mit 13 Abbildungen und dem Marktschiff-Gedicht vom Jahre 1596 als Anhang. Neue Ausgabe. Pp. (2) + 84, 8vo. (Frankfurt am Main: Verlag von Moritz Diesterweg, 1919.) [49]

(33) La Piazza Vniversale di Tvtte le Professioni del Mondo, e nobili et ignobili. Nvovamente formata, e posta in luce da Tomaso Garzoni de Bagnacauallo.

Al sereniss^{mo} et invittiss^{mo} Alfonso secondo da Este Duca di Ferrara Con Privilegio In Venetia, Appresso Gio. Battista Somascho MDLXXXV. Pp. (21) + 932 + (12), 4to. [50]

(34) Title under H. Sirturus (*1*) in Br. a. opt. Instr. 245. [50]

(35) Greeff, R. Weitere Erlasse des Rats von Venedig, die Zunft der Cristellarii betreffend (1330 bis 1505). *Deut. Opt. Wochschr.* 9 (1923) 100–1. [50]

(36) Title under G. Albertotti (*1*) in Bin. Instr. 273. [51, 52]

(37) Title under E. Bock (*1*) in Br. a. opt. Instr. 226. See pp. 4–5. [47, 52]

(38) Greeff, R. Hieronymus Sirturus. *Deut. Opt. Wochschr.* 4 (1919) 56. [52] See also v. Rohr, M. Hieronymus Sirturus. Bemerkungen zu dem Greeffschen Aufsatze gleichen Titels. *Ibid.* 4 (1919) 110.

(39) Title under C. A. Manzini (*1*) in Bin. Instr. 290. A German translation of The Manufacture of Dutch telescopes in Venice is to be found in *Die Naturwiss.* 8 (1920) 534. [52, 58] See also v. Rohr, M. Bausteine zur Geschichte des holländischen Fernrohrs. *Deut. Opt. Wochschr.* 9 (1923) 396–400.

(40) Title under P. Pansier (*1*) in Br. a. opt. Instr. 240. [53]

(41) v. Pflugk, A. Über Brillenmünzen und Medaillen. *Graefes Arch.* 105 (1921) 688–707 (1 Fig. and 4 Plates). (Fuchs-Festschrift.) Also reprinted v. Pflugk, A. Brillenmünzen und Brillenmedaillen. Pp. (2) + 20, 8vo; 1 Fig. and 4 Plates. (Halle a.S.: Riechmann & Co., 1921.) [53]

(42) v. Rohr, M. Ein alter Regensburger Lehrbrief. *Z. f. ophth. Opt.* 9 (1921) 69–72 (Plate). [54, 55]

(43) v. Pflugk, A., und v. Rohr, M. Einige Berichte über die oberdeutschen Brillenfabriken aus dem Ende des 18. und dem Anfang des 19. Jahrhunderts. *Centr. Ztg. f. Opt. u. Mech.* 44 (1923) 123–4, 134–5. [56]

(44) v. Rohr, M. Beitrag zur Geschichte der süddeutschen Brillenfabriken. *Z. Deut. Ges. f. Mech. u. Opt.* (1917) 83–9. [57]

(45) Title under M. v. Rohr (*24*) in Br. a. opt. Instr. 243. [57]

(46) Spectacles in a stone coffin. *Optician*, 19 (1900) 423. [57]

(47) McAllister, Francis M. *Opt. Journ. and Rev.* 46 (1920) 1157–8. [58]

(48) Wirzenius, P. See the review in *Z. f. ophth. Opt.* 7 (1919) 68–9. [58]

(49) P. Gasparis Schotti Regiscuriani e Societate Jesu, Olim in Panormitano Siciliae, nunc in Herbipolitano Franconiae Gymnasio ejusdem Societatis Jesu Matheseos Professoris, Technica Curiosa, sive Mirabilia Artis, Libris XII. Comprehensa; Quibus varia Experimenta, variaque Technasmata Pnevmatica, Hydraulica, Hydrotechnica, Mechanica, Graphica, Cyclometrica, Chronometrica, Automatica, Cabalistica, aliaque Artis arcana ac miracula, rara, curiosa, ingeniosa, magnamque partem nova & antehac inaudita, eruditi Orbis utilitati, delectationi, disceptationique proponuntur.

Ad Eminentissimum S. R. I. Principem Joannem Philippum Elector. Mogunt.

Cum figuris aeri incisis, & Privilegio.

Sumptibus Johannis Andreae Endteri, & Wolfgangi junioris Haeredum. Excudebat Jobus Hertz Typographus Herbipol. Anno M.DC.LXIV. Prostant Norimbergae apud dictos Endteros. Pp. (18) + 1044 + (8), 4to. [59]

On pp. 854–6 we find B. CONRAD's remarkable programme for the advancement of the telescope. As it seems to be totally forgotten I reprint it in its original form.

Epistola ad omnes Europae mathematicos, operis teledioptrices nuntia, missa a R. P. Balthasare Conrado Societatis JESU. Omnibus Reverendis, Praenobilibus, Clarissimis, & quovis alio titulo conspicuis per Europen Mathematicis. S. P. D. Balthasar Conradus S. I.

Ut quaedam conferam vobiscum, Illustres Animae, *pauca illa quidem, sed quae momenti ac ponderis in totam Rempublicam nostram Litterariam maximi esse videantur, injectus mihi jam pridem nescio quis perurget calor. Quocirca non temere sperarim fore, ut quanto major vos communis tangit cura boni, tanto huic meae ad vos Epistolae libentius otium e sublimibus illis vestris conceptibus rescindatis.*

Ex quo ergo primum (*nec pauci anni sunt*) *pernosse coepi Telescopium, didicique nec omnia ejusdem esse notae ac bonitatis, & plurima plurimum a summa abesse perfectione; ingens me invasit animus ac desiderium, imo & spes, eo aliquando deveniendi, ut certam ac infallibilem assequerer rationem, ad summam deducendi Telescopii perfectionem. Coepi itaque pervolvere inprimis Authores, quotquot de id genus Instrumento nancisci potui; tum speculari ipse, & multa cum animo putare meo; tandemque & operi manum, nec leviter aut oscitanter admovere, & varia, quae vel ad substantiam ipsam operis, vel ad modum pertinent, experiri. Sed & illico difficultates sese undique oggesserunt, nec paucae eae numero, nec leves superatu: tot certe, ac tantae, ut nisi DEUS constantiam in labore paene ferream concessisset, non mirum fuisset, si millies* ῥίψασπις *successum desperassem. Superavi tamen tandem cum divina gratia, quae se opposuerant, difficultates omnes; eoque artem perduxi, ut sequentia problemata praestare possim:*

I. Perfectam superficiem sphaericam, sive cavam in patinas, sive convexam in globos inducere; idque nec negotio, nec sumptibus adeo magnis.

II. Vitra perfecte concavare sphaerice, aut sphaerice convexare.

III. Perfectissime polire superficiem sphaericam tam cavam quam convexam, sine periculo figurae vitiandae.

IV. Oblatae cujuscunque patinae aut globi vitia, etiam occultissima, statim detegere.

V. Infallibiliter semper, ex materia apta, bonum elaborare Telescopium, ad quamcunque longitudinem.

Quorum problematum solutio quanti momenti sit in rem omnem Mathematicam & praecipue Astronomiam; quin & in usum totius generis humani; nemo unus Vobis melius aestimaverit: ut proinde longiore eam rem Vobis circuitu demonstrare ac depraedicare, minime sit necessarium.

Hanc autem ego mihi scientiam uti hactenus, nec sine ratione, occultam habui, ita & imposterum habere potuissem; vel certe ita solum propalare, ut extra Societatem nostram non emanaret; nisi me communis boni ratio ad alia consilia inclinasset. Itaque molior Opus justum ac integrum, quo totam hanc artem & quidquid de Telescopio dici aut quaeri potest, complectar; planeque ac dilucide, sine tenebris, omnem quam hactenus ingenio qualicunque demum, experientia indefessa, & sumptibus non modicis, scientiam in hoc genere consecutus sum, aperiam.

Quia vero unius hominis vix est, Opus tam omnibus numeris absolutum, quam & res postulat litteraria, & ipse ego desiderarem, in lucem protrudere; ideo aequum plane videtur, ut Vos etiam, Illustres animae, *vestras quasi symbolas in medium conferatis. Quapropter Vos omnes etiam atque etiam rogo, ut si quis vestrum in hoc genere aliquid aut invenit ipse, aut aliunde rescit, ultra ea quae vel Sirturus, vel Scheinerus, vel Rheita, vel Hevelius, vel Magnan, vel P. Schottus, vel Borellus prodidit, aut ego promitto; dignetur id mecum pro suo in commune bonum studio communicare. Vicissim bona polliceor fide, ita me ea gratia, ac humanitate usurum, ut nulli quidquam de sua laude ac nomine deteratur. De reliquo* radios *ego* vestros *radio omniscii Numinis ex animo commendo, in dignas scientia nostra, & aeternitate speculationes. Valete, & favete. Vratislaviae* 17. *Julii* 1658.

Vestrarum DD.

Servus in Christo
Balthasar Conradus.

(50) Oculus Enoch et Eliae sive Radius Sidereomysticus Pars Prima Authore Antonio Maria Schyrlaeo de Rheita Ord. Capucinorum concionat. et Provinciae Austriae ac Bohemiae Quondam Praelectore. Opus Philosophis, Astronomis, & rerum coelestium aequis aestimatoribus non tam utile quàm iucundum: Quo omnium Planetarum veri motus, Stationes, & retrocessiones, sine ullis epicyclis & aequantibus, tam in Theoria Tychonica, quàm Copernicana compendiosissime & iucundissime demonstrantur exhibenturque.

Hypothesis Tychonis quoad absolutam veritatem stabilitur ac facilior ipsâ Copernicanâ redditur, reformatur & ad simplicissimam normam & formam reducitur. Hisce accesserunt Novae harmonicae determinationes molium & proportionum Planetarum ad invicem. Item plurimae aliae novitates caelo ab auctore deductae. Probabilissima causa fluxus & refluxus Oceani. Ratio brevis conficiendi Telescopium astronomicum. Et ultimo Planetologium mechanicum et novum, quo paucissimis rotis veri omnium Planetarum motus iucunde exhiberi queunt.

Quia delectasti me Domine in factura tua: & in operibus manuum tuarum exultabo. Ps. 91.

Pp. (24) + 356; 2 Tables. (Antverpiae: Ex officina Typographica Hieronymi Verdussii. M.DC.XLV.) Cum Gratia & Privilegio. [60]

(51) Title under J. M. Conradi (*1*) in Bin. Instr. 278. [60]

(52) Prosser, R. B. The invention of the achromatic lens. *Optician*, 53 (1917) 203–5. [61]

(53) Title under W. Ch. Wells (*1*) in Br. a. opt. Instr. 248. See also M. v. Rohr's translation with some annotations: Zwei Aufsätze von W. Ch. Wells (1757–1817) (17. xii. 21). *Z. f. ophth. Opt.* 10 (1922) 12–25, 38–46, 68–80, 97–114. [61]

(54) Kurtze Anweiſung die Gläſer zu ſchleiffen und Perspective zuzurichten. Dresden, J. Ch. Miethe, 1680. Pp. 34 + (6); 62 Figs.

There are later editions of 1689 and 1741. See also *Centr. Ztg. f. Opt. u. Mech.* 41 (1920) 362, for some early evidence of the Perspektivmacher. [61]

(55) Title under Madame Alfred Heymann (*1*) in Br. a. opt. Instr. 235. [61]

(56) Charter of the spectacle makers' company. *Optician*, 19 (1900) 198–201. [62]

(57) Laurance, L. The optical craft in Great Britain—past and present. *Optician*, 25 (1903) 155–6, 160, 163–4. [62]

(58) [Woolley, S. W.] The spectacle makers' company and its examination. *Optician*, 16 (1898–9) 690, 692, 694, 698. See also Description of the common seal of the worshipful company of spectacle makers of London. *Ibid.* 13 (1897) 90 (Fig.). [62]

(59) Dunscombe, M. W. On the evolution of eye-glasses and spectacles. (Read before the Opt. Soc.) *Optician*, 45 (1912–13) 25–8 (163 Figs. in four groups). [62]

(60) Title under Ed. Pergens (*8*) in Br. a. opt. Instr. 240. [62]

(61) Geschäftsanzeige eines Berliner Optikers vor 170 Jahren. *Centr. Ztg. f. Opt. u. Mech.* 8 (1887) 154. [62]

(62) Thomin, [M.] Instruction sur l'usage des lunettes ou conserves, pour toutes sortes des vues. Marques auxquelles on peut connoître si les vues longues ordinaires ont besoin de conserves ou lunettes, des verres convexes qui leur conviennent, et des verres concaves qui sont propres aux vues courtes. Méthode pour se conserver la vue; avec une dissertation sur ce que les personnes âgées la recouvrent quelque fois dans un âge avancé.

Pp. 130, 12mo. (Paris: Cl. Lamesle, 1746.) [62]

(63) Title under J. Fr. Mey[en] in Br. a. opt. Instr. 238. [62]

(64) Title under W. Jones (*1*) in Br. a. opt. Instr. 236. See also M. v. Rohr's translation with annotations in *Centr. Ztg. f. Opt. u. Mech.* 43 (1922) 449. [63]

(65) Joh. George Leutmanns Neue Anmerckungen Vom Glaß-Schleiffen darinnen Die rechten Machinen die Gläſer durch Hülffe dreyer Bewegungen zu mehrerer Vollkommenheit zu bringen Desgleichen die Verziehung der Bilder durch Polyhedra leicht zu machen Nebſt allerhand neuen Optiſchen Inſtrumenten wie ſolche gemacht und appliciret, andere aber allbereit bekandte verbeſſert werden.

Pp. (16) + 96, 8vo; 21 Copperplates. (Wittenberg: Samuel Hanauer, 1719.) [63]

(66) Spiegelhalter, E. K. George Adams. *Optician,* 19 (1900) 275. [64]

(67) Title under W. Kitchiner (*1*) in Br. a. opt. Instr. 236. [64]

(68) Zur Feststellung des Publikationsdatum britischer und amerikanischer Patentschriften. *Patbl.* 13 (1889) 69–70, 77–8. [64]

(69) Title under J. Ayscough (*1*, *2*) in Br. a. opt. Instr. 225. [64]

(70) Title under B. Martin (*1*) in Br. a. opt. Instr. 238. [64]

(71) Title under A. Smith (*1*) in Br. a. opt. Instr. 245. [64]

(72) Title under J. Richardson (*1*) in Br. a. opt. Instr. 242. [64]

(73) Title under W. Storer (*1*) in Br. a. opt. Instr. 246. [64]

(74) Title under H. Dixon (*1*) in Br. a. opt. Instr. 230. [64]

(75) Title under G. Adams (*1*) in Br. a. opt. Instr. 224. [64]

(76) Title under D. Adams (*1*) in Br. a. opt. Instr. 224. [64]

(77) Title under T. Young (*1*) in Br. a. opt. Instr. 249. [64]

(78) Title under Chr. G. Hertel (*1*) in Br. a. opt. Instr. 235. [65]

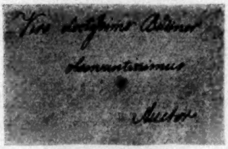
(79) Title under B. Franklin (*1*) in Br. a. opt. Instr. 231. [65]

(80) For J. G. A. Chevallier see p. 197 under No. 15. [65]

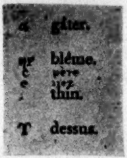
(81) Lenses, their history, theory and manufacture. Pp. 47 with Illustrations. (Rochester, 1906.) [65]

De corporis humani viribus conservatricibus Dissertatio.
Auctore Thoma Young,

Gottingae, Io. Chr. Dieterich, 1796
76 (2 *fol*) *small 8vo.*



Viro doctissimo Büttner
observantissimus
Auctor



gâter.

blême.
père
[illegible]
thin.

dessus.

[68] *VI.* [*Thesis*] *Lentis cristallinae in homine fibrae eodem ordine dispositae sunt quo in bove.*

VII. Sententia nuper (242) *de lentis cristallinae usu in oculo ad diversas rerum videndarum distantias accommodando proposita, neque nova erat* (241) *neque vera videtur* (243).

The above is copied from a card presented by Professor M. von Rohr to the Optical Society on the occasion of his delivering the Thomas Young Oration on 27th November, 1923. At the top is the title of Thomas Young's Göttingen dissertation. In the middle are photographic copies of the author's dedication to Professor Büttner and a portion of a table for pronouncing vowels in some languages, the alterations being in Thomas Young's handwriting. At the foot are the titles of the two theses VI and VII. The numbers (241–3) refer to the author's bibliograghy.

Professor von Rohr also presented to the Society a number of reprints of a translation* into German which he recently made of two of Thomas Young's publications. (A few copies are still available; application should be made to Professor Alan Pollard.) —Ed.

* "Zwei Abhandlungen von Thomas Young" ("On the Mechanism of the Eye" and "On Vision"), *Z. f. ophth. Opt.* 11 (1923) 102.

A SUGGESTED STANDARD TRIAL CASE AND SIMPLIFICATION IN OPHTHALMIC POLICY

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MS. received, 22nd November, 1923. Read and discussed, 13th December, 1923.

ABSTRACT. In a previous paper to the Society, the writer gave a review of the cumulative errors arising in present-day ophthalmic practice. It was suggested that plano-form trial lenses should supersede the existing symmetrical form. The object of the present paper is to describe such a standard trial case with specified thicknesses, diameters, tolerances, etc., which will introduce minimum confusion—actually none—in practice, will materially help both refractionist and manufacturer, and will remove the uncertainty between them. Policy of simplification and economy in ophthalmic manufacture is also suggested. That such a change is demanded is shown by the papers of Mr O. P. Raphael* and the writer† and the discussions on the same.

General Review.

The fundamental idea of the trial case is the estimation of a refractive error by a process of direct substitution. In order that a substituted spectacle lens shall reproduce the trial lens as far as distance correction is concerned, it should have the same back vertex power, or, in the correction of astigmatism, the difference of the back vertex powers for the meridians should be the same. It is necessary to define "equally effective" lenses in this way because generally the form of the spectacle lens is not the same as that of the trial lens. On the other hand lenses of different forms but equal back vertex power are *not* equally effective in near vision. For equivalence in near vision the back vertex convergences to the images of the near objects considered must be equal. Whilst not stated in these terms by M. Mayer, this condition will be called the Mayer equivalence. For exact equivalence in all respects the trial lens should be an exact replica of the spectacle lens as regards thickness and form. This policy is plainly impossible, but it will be shown that a plano-form trial case can be constructed, which first of all in itself constitutes a compromise satisfying the requirements within practical limits of error and secondly can be employed to give a second approximation to the actual form of lens which may be required, even to including thickness variations.

As the question is inevitably one of compromise, a trial lens should conform in shape and thickness to the most frequent form of lens used. This the plano-form does exactly. Thus spectacle forms range from symmetrical to deep meniscus lenses on a base of, say, − 9·0 D. Sphero-cylindrical lenses are plano-form in one meridian and approximately so in the other. The existing symmetrical standard form lies at the opposite extreme—both in positive and negative lenses—to the best-form bending towards which modern practice is tending. For the higher power negatives the plano-form is accurately best-form, for the higher power positives the actual single lens best-form is only approximate whilst the plano-form, besides being a very substantial compromise in that direction, is the form generally prescribed.

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* O. P. Raphael, "Standards of Accuracy for Ophthalmic Prescriptions." *Trans. Opt. Soc.* 24 (1922–23) 75.

† W. Swaine, "Paraxial Actions of Ophthalmic Lenses." *Ibid.* p. 79.

The mechanical construction of the plano-form is particularly favourable. By placing such lenses with plane faces together, useful approximations to other forms may be effected, e.g. symmetrical, deep menisci, and best-form. This particular observation is capable of important development. It implies that a refraction test may be made by a substitution of surfaces instead of complete lens units. *In other words the test is effected in terms of the units of the manufacturer*. The process is more fundamental and less likely to produce uncertainty between manufacturer and refractionist. It simplifies the former's problem.

This point is worthy of further attention with regard to a policy of numbering and specification of constants. The existing standards are numbered so that equal and opposite numbers neutralize, a policy which gives within the prescribed tolerances a vertex numbering, i.e. a symmetrical lens of nominal power + 20·0 D. neutralizes the negative marked − 20·0 D whilst their front and back vertex powers are also 20·0 D. The act of neutralization is rapid and convenient and should be retained as far as possible, but not to the sacrifice of the true function of the trial case lens. The writer does not consider that the neutralizing principle need be abandoned although it requires revision. Originally the idea of neutralization was summed up in the fallacious argument "that lenses which neutralize the same lens are equivalent." With unsymmetrical lenses (incidentally with the plano-form), the back vertex powers of the negatives must be equal and opposite to the front vertex powers of the positives for accurate and easy neutralization, when their adjacent surfaces (vertices) are in contact.

If, to avoid confusion with existing markings, both positive and negative lenses are marked according to their back vertex powers, equal numbers will not neutralize. Vice versa, a neutralizing numbering of unsymmetrical lenses is incompatible with the existing numbering. From a theoretical and absolute point of view, it is advisable to specify the back vertex powers of lenses since this measures the constant of the eye under test—the dioptral expression of the distance of the tip of the eyelash from the far point. It expresses the easily measurable back focal distance of the lens itself. It will not violate the indications of vertex focometers or lensometers. Many manufacturers have already spent considerable sums of money in producing various forms of lenses with back vertex power equal to the standards. These and many other smaller points demand a back vertex numbering.

To retain, however, the neutralizing principle, the front vertex powers of the trial case lens should be indicated as an integral part of the case, for reasons to be described in more detail later. A double designation of front and back vertex powers is almost unavoidable. It would still be necessary if the converse marking were adopted, since the designation of neutralizing or front vertex power violates existing standards and does not represent any absolute measure conveniently. Again, the simple addition rules with regard to powers of lens combinations in a trial frame hold more strictly with a back vertex numbering. The front vertex marking only favours the combination of lenses of powers which are nearly equal and opposite.

THE TRIAL CASE.

Table I shows the constants of the suggested standard plano-trial case lenses. They are based on the ordinary spectacle glass of index 1·523. The suggested outside diameter of 28 mm. (inclusive of rim when rimmed) differs considerably from the present standard of 38 mm. This is *not* for the purpose of reducing central substance, but to give a greater latitude in the lateral displacement of trial lenses before a patient's eyes. It is a matter of experience that at present it is impossible with existing lenses and trial frames to bring the lenses close enough together to

TABLE I. *Constants of Standard Trial Case.*

Spectacle glass. $n_D = 1{\cdot}523$. Standard diameter, 28 mm.

A	B	C	1	2	3	4	5	6	7
Back vertex power +	Front vertex power +	Vertex power −	Thickness in mm.		+ Back vertex		+ Front vertex		− Vertex
			Standard	Minimum	Maximum	Minimum	Maximum	Minimum	Minimum
0·12	0·12	0·12	1·0	0·7	0·14	0·09	0·14	0·09	0·09
0·25	0·25	0·25	1·1	0·8	0·27	0·22	0·27	0·22	0·22
0·50	0·50	0·50	1·2	0·9	0·52	0·47	0·52	0·47	0·47
0·75	0·75	0·75	1·3	1·0	0·77	0·72	0·77	0·72	0·72
1·00	1·00	1·00	1·4	1·1	1·02	0·97	1·02	0·97	0·98
1·25	1·25	1·25	1·5	1·2	1·27	1·22	1·27	1·22	1·23
1·50	1·50	1·50	1·6	1·3	1·52	1·46	1·52	1·46	1·47
1·75	1·75	1·75	1·7	1·4	1·77	1·67	1·77	1·67	1·70
2·00	2·00	2·00	1·8	1·5	2·02	1·94	2·02	1·94	1·96
2·25	2·24	2·25	1·9	1·6	2·27	2·18	2·25	2·18	2·21
2·50	2·49	2·50	2·0	1·7	2·52	2·43	2·50	2·43	2·45
2·75	2·74	2·75	2·1	1·8	2·78	2·67	2·76	2·66	2·70
3·00	2·99	3·00	2·2	1·9	3·03	2·91	3·02	2·90	2·94
3·50	3·48	3·50	2·4	2·0	3·53	3·39	3·51	3·38	3·43
4·00	3·97	4·00	2·6	2·0	4·04	3·88	4·00	3·85	3·92
4·50	4·46	4·50	2·8	2·0	4·54	4·37	4·50	4·35	4·41
5·00	4·95	5·00	3·0	2·5	5·05	4·85	4·98	4·85	4·90
6·00	5·92	6·00	3·4	2·5	6·06	5·82	5·97	5·80	5·88
7·00	6·88	7·00	3·8	3·0	7·07	6·79	6·94	6·74	6·86
8·00	7·82	8·00	4·2	3·5	8·08	7·76	7·90	7·66	7·84
9·00	8·76	9·00	4·6	4·0	9·09	8·73	8·85	8·58	8·82
10·00	9·68	10·00	5·0	4·5	10·10	9·70	9·77	9·48	9·80
11·00	10·59	11·00	5·4	5·0	11·11	10·67	10·69	10·37	10·78
12·00	11·48	12·00	5·8	5·0	12·12	10·64	11·59	11·24	11·76
13·00	12·35	13·00	6·2	5·5	13·13	12·61	12·47	12·10	12·74
14·00	13·20	14·00	6·6	6·0	14·14	13·58	13·33	12·93	13·72
15·00	14·03	15·00	7·0	6·5	15·15	14·55	14·17	13·70	14·70
16·00	14·85	16·00	7·4	7·0	16·16	15·52	15·00	14·55	15·68
17·00	15·64	17·00	7·8	7·5	17·17	16·49	15·79	15·32	16·66
18·00	16·41	18·00	8·2	7·5	18·18	17·46	16·57	16·07	17·64
19·00	17·16	19·00	8·6	8·0	19·19	18·43	17·33	16·82	18·60
20·00	17·89	20·00	9·0	8·5	20·20	19·40	18·06	17·50	19·60

test the effect of inward decentration of lenses in cases of narrow pupillary distance or to get them close to the eyes in cases of overhanging eyebrows. The smaller diameter also aids the visual examination of the centration during a test.

Columns A, B and C show the numbering appearing on the case. Columns A and C are the nominal or back vertex powers; Column B gives the neutralizing or front vertex powers which should be recorded opposite the corresponding positive lenses. It will be evident that Columns B and C give information to the manufacturer for the construction of the lenses or to the person who wishes to check the case by using the lens measure. The standard thickness of the negatives is 1 mm. with a tolerance of 0·5 mm. below and 0·2 mm. above. Column 1 shows the standard and maximum thickness of the corresponding positive lenses; Column 2 shows the minimum thickness allowed.

The maximum back vertex power of both positive and negative lenses is given in Column 3. The minimum powers are given in Columns 4 and 7 for positive and negative lenses respectively. These maxima and minima are based on the following:

Positives: 1 per cent. above, 3 per cent. below; negatives: 1 per cent. above, 2 per cent. below.

The tolerances of the surface powers (and therefore of the front vertex or neutralizing powers) are shown in Columns 5 and 6, being based on 1 per cent. above, 2 per cent. below for the positive lens. The same for the negatives are shown of course in Columns 3 and 7.

The limits of centration are those of the existing standards, as are also the limits of error for the prisms. The writer suggests that greater care be exercised by manufacturers in the marking of the base apex directions and cylinder axes: also that the tolerance of prism along the cylinder axis, Maddox rod, or Groove axis be kept below 0·2 prism dioptre. The thickness of the rim which may overlap the plane face of the lenses should not exceed 0·2 mm. Possibly an overlapping rim can be avoided because of the considerable edge thickness of the reduced diameter lenses whilst retaining central substance.

The following is an optical justification of the plano-form of lens.

THICKNESS OF POSITIVE LENSES.

The suggested standard and maximum thicknesses constitute a mean of the thicknesses of uncut lenses as tabulated by the American Optical Company. Thus, in the catalogue of this firm, the following "standard centre thicknesses of uncut lenses" for "double convex (34 × 44 mm.), peris. convex (42 mm. round eye) and sphero-cyl. lenses when + curve predominates" are for + 1·0 D, 1·5 mm.; for + 5·0 D, 3 mm.; for + 10·0 D, 4·7 mm.; + 15·0 D, 6·5 mm.; + 20·0 D, 8·8 mm. with an allowance 0·2 mm. each way. For rimless lenses these thicknesses are increased 0·4 mm., and when the lenses are for deep meniscus (− 6·0 D base) and 47 mm. round eye the standard and rimless thicknesses are each increased 0·2 mm. The average of these thicknesses for the above series of lenses are respectively 1·8, 3·3, 5·0, 6·8, and 9·1 mm. The suggested standard thicknesses are 1·4, 3·0, 5·0, 7·0, and 9·0 mm. respectively, figures which in addition satisfy the theoretical thicknesses of 00 eye (40 mm. large diameter) lenses having 1 mm. edge thickness. It will be observed, however, that the thicknesses for the weaker lenses are low. Such lenses will be used frequently in combination with more powerful ones both in testing and neutralizing, in which case it is advisable that the low power lens should be thin. For the same reason the minimum tolerance of all lenses is much greater than the maximum. They are appreciably larger than the existing standards, and probably in the extremely high power positive lenses are greater than would obtain in practice in the usual attempts to reduce weight. They satisfy, however, the mean thicknesses of the medium powers more frequently used, for which re-standardization is particularly required. The modern tendency to provide rimless ware with 0 and 00 sizes of eye demands that the existing standard be increased.

TOLERANCES OF POWER.

The tolerances of back vertex power of the negatives are closely those of the existing standards. On the other hand the positive tolerances differ—the existing standards allow a greater above error than below, whilst the suggested standard allows the reverse. This will help to maintain agreement with existing trial case markings as well as compensate for separations of combined lenses. The tolerances do not violate one another; thus the tolerance of back vertex power is not exceeded by taking the extreme tolerances of surface power and thickness.

It may be pointed out that, with the data supplied, a practitioner can test the case in all its particulars using a good lens measure and micrometer. The refractive index may be easily tested with a Pulfrich refractometer, using the plane contact face, or quite conveniently by using well-known reflection methods.

OPTICAL ANALYSIS.

In order to compare the trial case of plano-form lenses with that consisting of symmetrical lenses, certain leading powers are taken, namely, + 5·0, + 10·0, + 15·0, and + 20·0 D back vertex power. Using the thickness prescribed in Table I, the front surface combining power is calculated for symmetrical, plano-, − 6·0 deep meniscus, and − 9·0 deep meniscus lenses. These combining powers are given in Table II.

TABLE II. *Combining Surface in Dioptres.*

Back vertex power	Thickness mm.	Form			
		Equi-	Plano-	− 6·0	− 9·0
+ 5	3	+ 2·50	+ 4·95	+ 10·76	+ 13·62
+ 10	5	+ 4·96	+ 9·68	+ 15·20	+ 17·88
+ 15	7	+ 7·37	+ 14·03	+ 19·15	+ 21·66
+ 20	9	+ 9·70	+ 17·89	+ 22·54	+ 24·76

NEUTRALIZATION.

Using the data of Table II, the front vertex powers of these lenses and therefore their neutralizing powers at the front surface are calculated in Table III.

TABLE III. *Neutralizing Powers in Dioptres.*

Back vertex power	Form			
	Equi-	Plano-	– 6·0	– 9·0
+ 5	5	4·95	4·83	4·78
+ 10	10	9·68	9·32	9·14
+ 15	15	14·03	13·31	13·02
+ 20	20	17·89	16·75	16·21

Between the equi- and plano-forms there is a difference of neutralization in the case of the 20·0 lens of – 2·11 D; between the equi and – 6·0 deep meniscus – 3·25 D. A spectacle lens which neutralizes its prescribed power will overcorrect roughly by these amounts when a symmetrical trial lens is used.

On the other hand if the plano-form be used, and it is more than likely that a plano-spectacle of these higher powers would be used, and if the trial case of plano-lenses be used with the additional information permanently attached to the case describing the neutralizing powers (Column B, Table I), the error introduced averages around zero. For the medium powers the plano-neutralizing powers are intermediate between equi and – 6·0 D.M. and if the plano-figures be used, whilst the differences exceed slightly the tolerances of the trial lenses, they are probably just within a practicable tolerance*. They constitute a substantial control at least. These remarks apply particularly to the possible user of the case who does not realize fully the limitations of the neutralizing system.

As mentioned previously, it is this problem which necessarily involves the greatest compromise. The plano-form, however, allows of a more exact alternative. The deep meniscus form of the required spectacle may be reproduced by combining planos as already described, the combination being used in the trial frame. By neutralizing this combination as if it were a single unit, the actual spectacle lens should neutralize the same lens. "Lenses of the same form and thickness which neutralize the same lens have equal back vertex powers."

There is another practical point of importance which favours plano-form neutralizing lenses. Consider the contact surfaces of neutralizing lenses. First consider symmetrical lenses neutralizing a + 20·0 D; the contact curves will be:

+ 20. Plano-: – 8·94 against + 17·89. Difference: 8·94
+ 20. – 6·0 D.M.: – 8·37 against + 22·54. Difference: 14·17
+ 20. – 9·0 D.M.: – 8·10 against + 24·76. Difference: 16·66

Contrast this with the plano-form negatives which neutralize:

+ 20. Plano-: – 17·89 against + 17·89. Difference: 0
+ 20. – 6·0 D.M.: – 16·75 against + 22·54. Difference: 5·79
+ 20. – 9·0 D.M.: – 16·21 against + 24·76. Difference: 8·55.

Since the differences are not so great, there will be a relatively greater area of central contact, thus aiding neutralization.

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* They lie within the tolerances for a D.M. (deep meniscus) on – 6·0 base of 0 eye and corresponding minimum practical thickness.

Neutralizing planos with planos is actually reducing the combination to a parallel slab of glass and this will be the most common neutralizing process.

THICKNESS DIFFERENCES.

The tolerance of thickness is given as zero above and at maximum power 0·5 mm. below for positive lenses whilst for the negatives the limits are − 0·5 mm. and + 0·2 mm.

These were imposed to enable lenses to be combined by simply adding their back vertex powers and to allow for separations. Table IV shows the influence of thickness on the back vertex power and may also be used to find the necessary increase of combining surface power of the positive per millimetre decrease of thickness. Note that it is not suggested that, if this combining surface be so modified, the trial case indications of Column B, Table I—front vertex powers—should be altered.

TABLE IV. *Difference of Power in Dioptres per millimetre difference of thickness.*

Back vertex power	Form			
	Equi-	Plano-	− 6	− 9
+ 5	·01	·02	·07	·13
+ 10	·02	·06	·18	·24
+ 15	·04	·13	·30	·36
+ 20	·06	·21	·42	·59

COMBINING LENSES AND MAYER EQUIVALENCE.

The Mayer equivalence may be re-stated in the following words: the divergence of an object is not accurately additive to the back vertex power to give the convergence to the image for different forms of lenses. There is an extreme difference between symmetrical positives and − 9·0 D.M. whilst the plano-form is intermediate. In a precisely similar fashion plus and minus lenses placed immediately in front of a lens in a trial frame are not strictly additive, either with a front vertex or back vertex numbering. Generally an additional lens is weak and whilst the front vertex powers will be additive the error incurred by using a back vertex numbering is fairly small—is not negligible in a range of forms between symmetrical and deep meniscus—and may be neglected between the suggested plano-lenses and deep meniscus. Lenses applied at the back vertex add very accurately to a back vertex equivalent power, particularly for the weak combining spheres or plano-cylinders used in practice. In Table V is given what I describe as Effectivity Addition per Front Dioptre Addition; it holds for weak lenses up to about + 4 or + 5 placed in front of the corresponding lens forms.

Suppose an object (actual or produced by a negative lens, say − 3·0, placed in a parallel beam) to be 3 D in front of a + 20·0 D back vertex power lens. If the

TABLE V. *Effective Additions per Front Dioptre Addition.*

Back vertex power	Equi-		Plano-		− 6·0		− 9·0	
	+ 1	− 1	+ 1	− 1	+ 1	− 1	+ 1	− 1
+ 5	+ ·02	− 0·0	+ ·04	− ·01	+ ·05	− ·04	+ ·06	− ·05
+ 10	·04	·02	·08	·05	·12	·10	·14	·12
+ 15	·08	·06	·15	·13	·22	·18	·27	·20
+ 20	·15	·10	·27	·22	·35	·30	·40	·33

lens be infinitely thin, the image would lie at + 17·0 D beyond. Actually in the case of a plano-convex lens it would lie at a distance of

$$20 - 3 - 3 \times \cdot 22 = 16{\cdot}34 \text{ D}.$$

For the equi-form it would be at

$$20 - 3 - 3 \times \cdot 10 = 16{\cdot}70 \text{ D}.$$

For the − 6 D.M., it would lie at 16·10 D.

The differences of the effectivity additions give the variations from the Mayer equivalence per dioptre. Thus the difference between the symmetrical and deep meniscus − 9 base (+ 20 lens) is ·10 − ·33 = − ·23 per dioptre or nearly − ·70 D for reading distances. This is beyond a permissible allowance. With the suggested plano-form the difference only amounts to ·22 − ·33 = − ·11 D per dioptre or − ·33 D for reading distances. Thus the plano-form, halving the error at present accruing with symmetrical standards, brings it within permissible limits.

Variations in the case of negative lenses are negligible on account of the small thickness and restricted tolerances.

TRIAL FRAMES.

The suggested reduced diameters of the lenses is only proposed as an additional improvement. Objection may be raised as to the revolutionary effect in relation to the construction of trial frames and use with existing frames designed to receive 38 mm. diameter lenses. One reason has already been advocated for this. If restandardization can include this novelty, the new frame required may very conveniently introduce new features, particularly in the construction of the bridge to prevent wobble and to distribute the load. Further, since the plane faces of the lenses allow closer contact and do not bulge, it permits of a re-design with regard to cell separations if a cell should be required there at all. The plane back vertex of the positives and the constant central thickness allow a constant position of all lenses relative to their mounts.

Objection may be raised against the smaller diameter lens in that neutralization may be rendered more difficult. But the same applies to lenses which are too large and the writer does not consider it important.

OPHTHALMIC MANUFACTURE.

It has come to the writer's knowledge that some manufacturers have adopted methods of numbering their curved tools to suit a rather temporary practical convenience. Thus in the first place a tool is described as the tool which if used with spectacle glass and average thickness will give a symmetrical lens of power stipulated by the tool.

Thus taking Table II, a tool giving an actual surface power of + 9·70 would be described as a + 20 tool since if used to make a symmetrical lens the nominal power of the lens will be + 20. Obviously this leads to unnecessary multiplication of deep curve tools when carried to a designation for meniscus and plano-lenses. It is also a hopeless proceeding when making necessary modifications for thickness. It must lead to confusion, inaccuracy, and expense. A much saner proposal would be to describe the tool in terms of the power of the surface which it produces when using spectacle glass. The employment of the plano-case, however, means using well-defined surfaces, considerably limited in number, for all forms of lenses. In fact, to a first approximation, the spherical and cylindrical tools required by the manufacturer are those given in Table I. If thickness modifications are made, the adjustment can be carried out, at the lower power surface, by increasing slightly the number of lower power tools, instead of increasing the number of the deeper curves. All that the storekeeper or man in charge of the tools requires is Table I which therefore contains the main details of ophthalmic manufacture. If it be thought worth while (the writer does not think it advisable), surfacing tools could be given the round number of Columns A and C which is the back vertex power of the plano-form lens produced. The absolute powers of the tool would, of course, be that of Columns B and C. This last policy will cause the minimum of derangement, and will straighten out the difficulties of the manufacturer. The time has come when strict adherence to base curves of 3, 6, and 9 D has very doubtful economic advantages.

Additional Note. Whilst engaged in correcting the proof of this paper, an article appeared in the current issue (30th Nov. 1923) of the *Optician* by Mr Whitwell: "On the Best Form of Spectacle Lens. XXX. Tolerances." Mr Whitwell gives the depth of focus limits imposed by the Hooke-Helmholtz one minute resolving power. In effect the equations derived by Mr Whitwell are

Tolerance in Power $= \pm (\cdot 064 - \cdot 001D)$ for a distant object

$= \pm (\cdot 067 - \cdot 001D)$ for an object 3·0 D away,

in which D is the vertex power of the correcting lens. These formulae give the following figures:

Vertex power	Tolerance in Dioptres	
	Distance	Near
+ 20	·044	·047
+ 15	·049	·052
+ 10	·054	·057
+ 5	·059	·062
+ 1	·063	·066
− 1	·065	·068
− 5	·070	·072
− 10	·074	·077
− 15	·079	·082
− 20	·085	·087

It will be seen that these tolerances are very much narrower than those given by the writer in this paper. In order to anticipate possible discussion around the point, reasons are given here for assuming tolerances which are proportional to the powers of the lenses.

Practical experience shows that the higher ametropic defects are less sensitive to small differences of power. The reasons for this the writer can only surmise; they may be retinal or optical in origin. Unfortunately the writer has no figures to back up this observation drawn from experience, but they may be easily obtained from an analysis of the ordinary visual acuity records of refractionists. This implies that the Hooke-Helmholtz one minute resolving power does not hold for the higher refractive errors corrected. Indeed the writer considers that such resolution is abnormal even for normal eyes with the keenest vision*. The writer felt that the existing standard tolerances were based on such considerations and did not feel any justification for any serious modification.

If much finer tolerances should be adopted than are suggested in this paper, it will most likely mean the abandonment of the neutralizing principle, as the accuracy of this process is only slightly greater than the tolerances.

Then again there are the more controversial technical difficulties of manufacture and sight-testing. "Practical" manufacturers and refractionists are likely to agree that finer limits of tolerance are unnecessary; the writer would endorse this point of view.

In conclusion the writer wishes to emphasize these facts: The individual errors arising in present-day practice are mutually cumulative to degrees which cannot be ignored. By the use of the plano-form case these cumulative errors are absolutely controlled with no violation of routine practice.

DISCUSSION

Mr A. H. Emerson: I am here to-night in a dual capacity, as a manufacturer and as a member of the Standards Committee which, under the Chairmanship of Mr Lionel Laurance, is considering and has nearly completed recommendations for Standard Trial Lenses. This committee includes representatives of the Wholesale and Manufacturing Association as well as of the principal Ophthalmic Societies. I ought not to anticipate the findings of this committee, but I have authority for saying how glad it is of another advocate of the plano-form and of a smaller lens, both of which are recommended by it. The committee does not altogether agree with some of Mr Swaine's suggestions, as will be seen when the report is published.

As a manufacturer I have advocated the return to this form for many years now. Our investigation into this matter has revealed that they were in use, as early as, if not before, the equi-curved form.

Mr Swaine's remarks on the nomenclature of surface grinding tools for mass production are rather amusing. It is not merely a question of an infinite number of variations but of providing a large number of each. I can call to mind one particular sight curve of which we use at Mill Hill many more than one hundred tools. For this reason alone manufacturers will welcome the standardization not only of trial case lenses but spectacle lenses in general. Anticipating this, we have provided for and are ready to produce guaranteed plano-convex and plano-concave lenses so soon as the people of this country desire English made lenses.

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* W. Swaine, "Acuteness of Vision." The Optical Initiate in *Optician* (10th Aug. 1923), p. 446

Mr T. F. Connolly: Chiefly owing to the fact that lenses possess thickness, a consistent and suitable nomenclature, for ophthalmic and manufacturing purposes, for powers of positive and negative lenses presents difficulty. The author's scheme appears a satisfactory method of overcoming this difficulty. Apart from changes in the standard thicknesses and the suggested change of diameter, two elements in the proposals are of special importance. The first is the use of plano-convex and plano-concave lenses and the second is the specification of both front and back powers for the positive lenses.

The specification of the India Store Department for trial cases already presents plano-convex and plano-concave lenses on a neutralization basis. In the author's Table I the Columns B and C would, therefore, according to this specification, be identical. It is considered, even on the above basis, that plano-lenses are an improvement on equi-lenses and the change is in the direction urged by Mr Swaine in the present paper. The equivalence of Columns A and C, as suggested in the paper, is a further ophthalmic improvement, while the needs of the manufacturer, etc., are met by Column B. In fact the author's suggestions, if adopted, would conform to the above specification, which is practically only concerned with powers up to 8 D, with differences amounting only to the tolerances as a maximum. If the author would accept metal rims, to bring the diameter of his lenses up to the standard, I would be in almost complete agreement. Any changes in the standard diameter of the lenses should be adopted only after very careful consideration of all factors. Existing trial frames take 38 mm. lenses and so "vested interests" necessitate a "conservative" attitude in this matter.

Mr J. Guild: I disagree with Mr Connolly's suggestion that the lenses should be mounted so as to fit existing trial frames. One of the chief advantages of the smaller size lens would be that a lighter and more compact frame could be employed. Most of the existing frames are so heavy and cumbersome as to produce serious discomfort by their pressure on the nose and the strain on the facial muscles generally, and there is no doubt that with many patients these abnormal conditions appreciably affect the vision during test. I hope that the adoption of the smaller lens will necessitate the re-design of frames and that designers will remember that these frames have not only to accommodate lenses but have to be worn by patients without inducing such unusual muscular reactions as, possibly, to vitiate the test.

Mr T. Smith: As there is a committee sitting which some of us now hear for the first time from Mr Emerson is considering the standardization of trial lenses, including their form and size, it is right to point out that this Society has a Standards

Committee which in years past has been the acknowledged authority on this subject in this country. That Committee has not been dissolved, and I suggest as the proper course that no new standards should be proposed for adoption here until they have been submitted to this Optical Society Committee and their views have been considered. I think I am right in saying that the question of lens form was very carefully considered by that Committee, who fully appreciated the advantages of the plano-form, but were deterred from recommending it because American practice had at that time an almost overwhelming influence for purely economic reasons.

The present proposal is different from previous suggestions using lenses of this form in that positives and negatives of the same denomination do not neutralize when their curved surfaces are in contact. This special feature must be kept in mind or it may lead to misunderstanding. For instance, if the India Stores Department were to accept trial cases made according to Mr Swaine's scheme and also sets with plano-lenses on any of the bases suggested hitherto, without particularly calling the attention of the users in India to the distinction between them, some of their correspondence might be more lively than polite.

Mr A. Whitwell: I agree mainly with what Mr Swaine has said in his paper, but there are one or two small points which I should like to discuss.

I agree that the lenses of the trial case should be plano-convex or plano-concave instead of double convex or double concave as they are at present.

I also agree that it is best to mark or number the lenses with the back vertex power, that is the power as measured from the plane face.

If in addition we know the power of the curved surface, which is of course the front vertex power, then we also know the Gauss or cardinal power and we also know the reduced thickness $\frac{t}{\mu}$ which is equal to the difference of the vertex powers divided by their product.

$$D_{v_1} = D_{v_2}\left(1 = \frac{t}{\mu} D_{v_1}\right) \quad \text{or} \quad \frac{t}{\mu} = \frac{D_{v_2} - D_{v_1}}{D_{v_1} D_{v_2}}.$$

This is a very simple formula for checking the axial thicknesses of the positive lenses.

For example, from Table I, if we take the back vertex power to be 4D and the front vertex power 3·97D, the thickness should be

$$\frac{\mu \times \cdot 03}{15\cdot 88} = \cdot 00287 \text{ or } 2\cdot 9\,\text{mm}.$$

Mr Swaine gives the standard thickness as 2·6 mm. This difference of thickness, however, only makes a difference in the power of one unit in the second decimal place. Taking Mr Swaine's thickness to be correct, the front vertex power should be 3·98 instead of 3·97.

As regards the thicknesses of the positive lenses I should like Mr Swaine to have fixed the standard thickness by a definite rule instead of the more arbitrary plan he has adopted. I suggest that the standard thickness should be that corresponding to a definite diameter of lens of the same power, say 38 or 40 mm.

In my view the tolerances given in Columns 3–7 of Table I are too large. I do not know sufficient about it to say to what accuracy in power a trial lens can be ground, but I think the trial lenses should be made as accurately as possible.

Mr Swaine says "practical experience shows that the higher ametropic defects are less sensitive to small differences of power." This may be because we have not at present sufficiently accurate tests. It may be that some day some one will come along with test charts or with some method of testing by which one could detect a difference of power say of ·1 D in a higher power spectacle lens. In any case ought we not to consider a trial case as a set of lenses of precision which should be made as near the power which they purport to be as they can be made with due regard to cost?

Mr H. H. Emsley: It is interesting to hear from Mr Emerson that the Standards Committee of which he is a member has been considering the question of a plano-lens trial case. I understood, however, that they were not dealing with anything fundamental, but only with mechanical details connected with ophthalmic ware. I would like also to point out that the trial lens suggested in this paper differs in some respects from that recommended by Messrs Lionel Laurance and Oscar Wood in their recent articles in the *Optician*.

In connection with Mr Connolly's remarks, the new lenses of small diameter can be mounted in large rims to fit existing trial frames; but I believe Mr Swaine recommends the adoption of a newly designed trial frame which will allow of the necessary adjustments and will at the same time attempt to remedy some of the mechanical defects of most existing trial frames, which are not what they might be. Mr Guild appears to agree with the last phrase.

There is the type of frame that is carried on a bracket fixed to the wall or a stand or chair; frames of this kind do not appear to be used in this country, perhaps because of the uncertainty as to whether the patient is keeping his (or her) head steadily in position against the stops provided. In America, I have been informed, the head is sometimes shaped in some way to the frame.

I was interested to hear Mr Smith remark that the decision to adopt symmetrical trial case lenses in 1908 by the Optical Society's Standard Committee (Trial Case) was influenced by the weight of American opinion. The ophthalmic industry of this country seems to have been so influenced for a long time. I do not know why this should be; there are workers over here whose line of thought is equally up-to-date and progressive, if not more so.

Mr Whitwell may of course be quite correct in stating that the visual acuity in cases of high ametropic errors may be found to be more sensitive if research were carried out on these lines. I rather think, however, that Mr Swaine's statement has much experience of his own behind it.

Mr Swaine (communicated): The reply may be dealt with conveniently under subject headings:

Standards Committees and Standardization.

(Messrs Emerson, Smith, and Emsley.)

My only notification of the existence of the committee of which Mr Emerson is a member was a small paragraph in the *Optician* and a brief reference by Mr Raphael in his paper to this Society a year ago. It is to be regretted that the public have not been made more fully aware of the scope of this committee. My own opinion is that a committee undertaking a wide reconstruction scheme, involving, for example, a decision relating to the re-design of trial cases should be absolutely representative and authoritative and preferably international.

I am interested to read that at Mill Hill provision has been made for the production of guaranteed plano-convex lenses. I am sure many people besides myself would like to know precisely on what numeration basis these lenses are to be produced and whether the back vertex power of the present day symmetrical standards is reproduced conveniently.

Lack of information around such important matters as those just mentioned gives rise to a general "liveliness," one form of which is anticipated by Mr Smith. One finds, for example, that the patient returns dissatisfied to his oculist who informs the optician; then the prescription house hears something about it, whereupon departments fall out before the manufacturer comes in for his share of the blame. I venture to suggest that the possible liveliness pointed out by Mr Smith would be very healthy as it is capable of so easy an explanation. Thus Columns A, B and C of Table I which are recorded on the case state clearly the exact numerical position. The influence of this particular observation is felt in all the stages of spectacle construction: it smooths out the friction which arises with the present symmetrical standards and in the new standards does not introduce new difficulties with regard to a back vertex numbering. For example, Column B, Table I, could very well be pasted in the cases of symmetrical lenses as indicating the neutralizing lenses for plano- and deep meniscus lenses. This means that the suggested standard may be used at the same time as the symmetrical standards already in active use, which latter can therefore die a natural death whilst the new plano-case grows up.

With Mr Emsley I was interested to hear that American opinion was influential at the last Standards decision and from a hint dropped by Mr Raphael it appears that America only is being consulted by the committee mentioned by Mr Emerson. I wonder at the absence of any reference to French and German work.

Form, Thickness, and Numbering.

(Messrs Connolly, Emerson, and Whitwell.)

I appreciate the general agreement on the question of lens form. Mr Whitwell and Mr Connolly agree with the numbering. I can only surmise that Mr Emerson's Committee disagree with the suggestions made here on thickness or numbering or both.

The Gowlland case of plano-lenses was made with thin lenses mounted in annuli to bring the diameter to the standard 38 mm. These lenses being thin give allowable equal back and front vertex powers and therefore do not violate the existing standards, either as regards back vertex power or neutralization. They do not correct the neutralizing principle when applied to thick lenses and they do not satisfy the Mayer near equivalence, which also introduces the thickness factor. Beyond the simple question of form they offer little advantage over the symmetrical form.

If thickness compensating devices are introduced to produce a gradation of thickness (rough though it need be), the resulting solution lends itself only to a front vertex or neutralizing numbering with surface powers more or less integral. The numbering will not agree with the existing back vertex power numbering. During the period of transition two incompatible systems will be in use with consequent further possibilities of confusion, especially if the system is not universally adopted. As remarked previously, the case suggested in the paper is not open to this objection.

In reply to Mr Whitwell the average thicknesses stipulated may be calculated from

$$t = (\cdot 4\, D + 1) \text{ mm.},$$

where D is the *back* vertex power. As mentioned in the paper, they are the average of the A. O. Co's lenses as stated in their catalogue. These thicknesses are higher than will obtain in practice, for the theoretical thickness of lenses, say 40 mm. in diameter and 1 mm. edge thickness, is given by

$$t = (\cdot 4\, F + 1) \text{ mm.},$$

where F is the front surface power of the plano-lens. This greater thickness was adopted mainly to accommodate the influence of the employment of deep meniscus spectacle lenses, which are in relatively greater use than the symmetrical type. Reference to Table III shows that the front vertex power (*i.e.* neutralizing power) is smaller than the back in proportion to the bending and to the thickness. By choosing thick standards, the neutralizing powers are a practical compromise between the practical plano- and deep meniscus forms (see page 78).

Lens Diameter.

(Messrs Connolly, Emerson, Guild, and Emsley.)

Whilst there is a general agreement on the suggested reduction of diameter, as Mr Connolly rightly points out, "vested interests" must receive some consideration. I believe, however, that the question is capable of adjustment to the general requirements. I suggest that a pair of annular adapters be provided with the case which will receive the new standard lenses whilst employing the old type of trial frame. In any case the central substance allows of the manufacture of full size 38 mm. lenses, or alternatively, metal annuli may bring the diameter up to the old standard. I agree with Mr Guild that many modern frames are instruments of torture, in addition to possessing unavoidable mechanical weaknesses owing to the large diameter lens in use.

Tolerances.

(Mr Whitwell.)

I agree with Mr Whitwell's main contention that trial lenses should be as precise as is practicable. I assume, however, that cost must be seriously considered. If we therefore extend the tolerances, as Mr Whitwell does, to a resolution limit, we may then observe that the highest power of a positive lens or the lowest negative limit is more definitely fixed on such a basis. The lower positive and the higher negative limits are fixed by the differences of accommodation which may be allowed. At the same time it is worth recording that alleviation or prevention of harm are the primary functions of a correction, whilst the securing of acute vision is only secondary. The end determination of the corrective lens is generally influenced by the indications of other tests, muscle balance, latent hyperopia, etc. The writer had not experienced any inconvenience from the tolerances with the existing standards and consequently had chosen them as a basis for the present standard.

If cost of production is not of such paramount importance, I am in favour of rather narrower limits. Mr Whitwell's figures could then be adopted as being certainly well within limits of ocular resolution. Alternatively, the writer proposes that the Hooke-Helmholtz one minute angle may be superseded as follows:

For defects 1·0 to 5·0 ... 90 seconds resolution
" 5·0 " 10·0 ... 110 " "
" 10·0 " 20·0 ... 150 " "

THE PRIMARY AND SECONDARY CONSTANT MAGNIFICATION SURFACES OF THIN LENSES

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MS. received, 26th October, 1923. Read, 13th December, 1923.

ABSTRACT. The surfaces of constant magnification on which the primary and secondary focal lines for a thin lens are situated form families of similar surfaces, and lie between easily constructed surfaces (spheres for the secondary surfaces) determined by the power of the lens together with the Petzval sum for the one limit and the sum of the lens curvatures for the other.

Coddington's equations for the determination of primary and secondary conjugate foci when light is refracted at a single surface are

$$\mu' V' \cos^2 \phi' - \mu U' \cos^2 \phi = K \qquad \ldots(1)$$

and

$$\mu' V - \mu U = K \qquad \ldots(2)$$

respectively, where μ is the refractive index for the first and μ' for the second medium, ϕ and ϕ' are the angles of incidence and refraction for the principal ray, U and V are respectively the reciprocals of the distances of the secondary object and image points from the point of refraction—that is, the curvatures at the point of refraction of the incident and emergent wave fronts—and U' and V' are the corresponding primary quantities. K, the refracting power associated with this ray, is given by

$$K = R(\mu' \cos \phi' - \mu \cos \phi) \qquad \ldots(3),$$

where R is the curvature of the refracting surface, and ϕ and ϕ' obey the law of refraction

$$\mu' \sin \phi' = \mu \sin \phi \qquad \ldots(4).$$

If instead of a single refraction the light passes through a number of surfaces which are sensibly in contact, so that the U and U' of one surface are indistinguishable from the V and V' of the preceding surface, and if further all the surfaces are parallel to one another where the principal ray meets them, the series of equations corresponding to (1) and (2) yield when added together other equations of the same type, the μ, ϕ, U, and U' relating to the first medium and the μ', ϕ', V, and V' to the last, while K represents the sum of the powers of the individual surfaces. In the most important case the refractive indices of the two external media are equal, and are given the conventional value unity. If ψ is the value of ϕ for this medium, the K for a typical surface may be regarded as the sum of $R(\cos \psi - \mu \cos \phi)$ and $R(\mu' \cos \phi' - \cos \psi)$, and by grouping together in pairs the surfaces separating any particular medium of index μ, $R(\mu \cos\phi - \cos\psi)$ is obtained as the contribution to K, where R is now the "total curvature" of the thin lens of this index. If there is more than one lens of the same material, R may be taken as the sum of the total curvatures of all lenses of the one glass, and K is obtained by summing the contributions for every kind of glass present. Since it is only the sum which enters into the final equation, it follows that for given object surfaces the same image surfaces are obtained whatever the order in which the component lenses are arranged, however the individual glasses may be divided into a number of separate lenses provided the total power of each kind of glass remains unaltered, and however the shapes of any or of all the components may be changed. In particular the curvature and astigmatism in the images formed by all thin achromatic systems constructed from the same two glasses will be identical.

In nearly all cases the conjugate surfaces of most interest are those for which there is a constant degree of magnification or minification. If the magnification is m the primary and secondary surfaces are obviously found by imposing the conditions

$$U = mV, \qquad U' = mV'$$

giving

$$U = U' \cos^2\psi = Km/(1 - m)$$

$$V = V' \cos^2\psi = K/(1 - m),$$

showing that all the primary surfaces are similar to one another, and likewise all the secondary surfaces. The primary surfaces are deducible from the secondary by shortening every radius vector in the ratio $\cos^2\psi : 1$ whatever the shape of the secondary surfaces may be; this enables attention to be focussed on one of these sets only, and the secondary is chosen because these surfaces are of a much simpler shape than the primary surfaces. It may be noted from the general equations that there are only two cases in which the primary and secondary surfaces coincide: these are when U, V, U', and V' are infinite, the conjugate surfaces being situated at the lens and the magnification being unity; and where (1) and (2) are derivable from one another in virtue of (4), that is when $m = \mu/\mu'$. These examples correspond to the refracting surface itself and to Young's aplanatic spheres in the case of a single spherical refracting surface, and become coincident with one another when the two external media are alike. The vanishing of the astigmatism to the second order for surfaces through the point of refraction involves the absence of astigmatism for surfaces in general in this neighbourhood.

Since all the surfaces are similar to one another it is sufficient to consider a particular example, and the most convenient is that for which $m = 0$. U then vanishes, that is to say the object is at infinity, and the whole of the surfaces may be deduced from the particular case $V = K$.

Consider first the case in which the system consists of a single lens of refractive index μ. Since $K = R(\mu \cos\phi - \cos\psi)$ and $\mu \sin\phi = \sin\psi$, the polar equation of the surface is

$$v = \frac{1}{V} = \frac{f}{\mu + 1}(\cos\psi + \mu\cos\phi),$$

where v is the distance from the lens vertex to the image surface in the direction ψ, and f is the focal length of the lens, so that

$$\frac{1}{f} = \kappa = R(\mu - 1).$$

Now from Fig. 1 it is apparent that the curve

$$v = a \cos\psi + b \cos\phi$$

represents a circle of radius b with its centre at $(a, 0)$, provided the condition

$$a \sin\psi = b \sin\phi$$

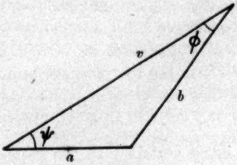

Fig. 1

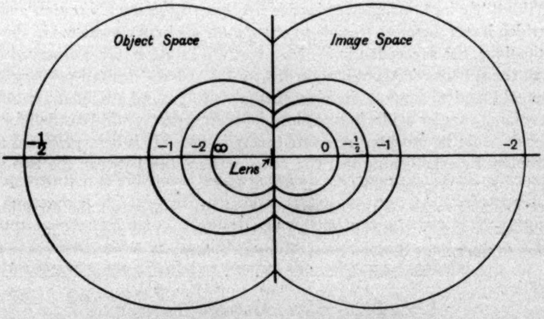

Fig. 2. The numbers give the magnifications.

is satisfied. Thus in the case of a single thin lens the secondary focal surfaces are spheres whose centres divide the axial distance between the lens and the axial image point in the ratio $1 : \mu$, or if ϖ be written for the reciprocal of the refractive index, in the ratio $\varpi : 1$. It follows that the curvature of the image surface is $-(1 + \varpi)$ times the curvature of the wave surface as it emerges from the lens. A series of these surfaces are shown in section in Fig. 2 for a lens of refractive index 1·5.

When there are lenses of various kinds of glass present, the surfaces are in general less simple and the only well known results are those which give the shape of the surfaces in the immediate neighbourhood of the axis. These are equivalent in this case to the statement that the factor $-(1+\varpi)$ still applies if ϖ for the complete system is calculated from the formula

$$\varpi = \frac{\Sigma\kappa_p\varpi_p}{\Sigma\kappa_p} \qquad \ldots(5),$$

the summations extending over all the lenses. This definition may be regarded as an equation for finding a mean velocity of the light in traversing the system of lenses, and the Petzval theorem states that the mean so derived gives the curvature of the image surfaces in the immediate neighbourhood of the axis. Apart from this theorem we might have considered other alternatives which agree with the exact result for a single lens. For instance, we might have investigated a mean "slowness" or refractive index given by

$$\mu = \frac{\Sigma R_p\mu_p}{\Sigma R_p} \qquad \ldots(6)$$

and compared the actual image surface with the sphere of curvature $-(1+\mu^{-1})$ times that of the emergent wave surface. The actual position is that (5) is known to be correct in the neighbourhood of the axis and (6) definitely in error. Moreover Mr Wilfred Taylor*, using an objective free from spherical aberration and coma, with which it was therefore feasible to observe the surfaces considered in theoretical investigations, has succeeded in showing that the actual surfaces observed lie very close to the sphere constructed according to (5) and the derived primary surface. This would tend to support the view that (5) is in general a reliable formula even for very large angular fields, but much wider verification would be called for before this result could be accepted as a safe generalization. It is here proposed to limit the problem by establishing that the actual surface lies between the two spheres derived from the expressions (5) and (6).

Let the reciprocals of the chords of these two spheres in the direction ψ be denoted by I and J respectively, and for brevity write $\sin^2\psi = \alpha$. Then the equation to the sphere derived from the mean velocity is

$$\frac{I}{\Sigma\kappa_p} = \frac{(1-\varpi^2\alpha)^{\frac{1}{2}} - \varpi(1-\alpha)^{\frac{1}{2}}}{1-\varpi}$$

and that from the mean refractive index is

$$\frac{J}{\Sigma\kappa_p} = \frac{(\mu^2-\alpha)^{\frac{1}{2}} - (1-\alpha)^{\frac{1}{2}}}{\mu-1},$$

while the real surface is given by

$$V = \Sigma R_p\{(\mu_p^2-\alpha)^{\frac{1}{2}} - (1-\alpha)^{\frac{1}{2}}\}.$$

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* *Trans. Opt. Soc.* 24 (1922–23) 321.

These may be expanded in series of ascending powers of α giving

$$V = \Sigma\kappa_p \Big\{1 + \tfrac{1}{2}\alpha\varpi_p + \tfrac{1}{8}\alpha^2\varpi_p(1 + \varpi_p + \varpi_p{}^2) + \ldots$$
$$+ \frac{(2n-2)!}{2^{2n-1}\,n!\,(n-1)!}\,\alpha^n\,\varpi_p(1 + \varpi_p + \varpi_p{}^2 + \ldots + \varpi_p{}^{2n-2}) + \ldots\Big\},$$

$$\frac{I}{\Sigma\kappa_p} = 1 + \tfrac{1}{2}\alpha\varpi + \tfrac{1}{8}\alpha^2\varpi(1 + \varpi + \varpi^2) + \ldots,$$

while J is derived from the I formula by putting μ^{-1} for ϖ. From the definition of ϖ it follows that

$$V - I = \sum_{n=2}^{\infty}\frac{(2n-2)!}{2^{2n-1}\,n!\,(n-1)!}\,\alpha^n\,\{\Sigma\kappa_p\varpi_p{}^2(1 + \varpi_p + \ldots + \varpi_p{}^{2n-3})$$
$$- \varpi^2(1 + \varpi + \ldots + \varpi^{2n-3})\,\Sigma\kappa_p\}.$$

The lowest term on the right is of the fourth order in the inclination, indicating that V and I are in contact near the axis, as is required by the Petzval theorem. As the range of values of the individual ϖ's is small, and consequently the value for the complete lens will be nearly equal to that for a component, unless the composition of the lens is of an extreme character, the signs of all the terms on the right will tend to agree with that of

$$\Sigma\kappa_p\varpi_p{}^2 - \varpi^2\Sigma\kappa_p$$

or

$$\{\Sigma\kappa_p.\Sigma\kappa_p\varpi_p{}^2 - (\Sigma\kappa_p\varpi_p)^2\}/\Sigma\kappa_p$$

or

$$\Sigma\kappa_p\kappa_q(\varpi_p - \varpi_q)^2/\Sigma\kappa_p,$$

where the summation is taken over all pairs of component lenses. In achromatic lenses this sum clearly tends to be negative, as is seen by considering a doublet lens as a simple case and more generally by comparing it with

$$2\Sigma\kappa_p\kappa_q = (\Sigma\kappa_p)^2 - \Sigma\kappa_p{}^2,$$

this being negative as individual lenses tend to be at least as powerful as the achromatic combination constructed from them. It follows that I is greater than V, or the Petzval theorem gives an exaggerated estimate of the departure of the image from a plane in the outer parts of the field of view.

Comparing now the actual surface with the "slowness" sphere,

$$V - J = \sum_{n=1}^{\infty}\frac{(2n-2)!}{2^{2n-1}\,n!\,(n-1)!}\,\alpha^n\,\{\Sigma\kappa_p\varpi_p(1 + \varpi_p + \ldots + \varpi_p{}^{2n-2})$$
$$- \mu^{-1}(1 + \mu^{-1} + \ldots + \mu^{2-2n})\,\Sigma\kappa_p\},$$

there being now a term present varying as the second power of the inclination, so that this sphere does not give the correct image curvature near the axis. As before the signs of the terms in general will follow those of the lowest terms

$$\Sigma\kappa_p\varpi_p - \mu^{-1}\Sigma\kappa_p.$$

Write

$$j_p = \kappa_p + R_p, \quad \text{so that} \quad \mu = \frac{\Sigma j_p}{\Sigma R_p} = \frac{\Sigma j_p}{\Sigma j_p\varpi_p}.$$

Then

$$
\begin{aligned}
&\Sigma\kappa_p\varpi_p - \mu^{-1}\Sigma\kappa_p \\
&\qquad = \Sigma j_p\varpi_p\,(1-\varpi_p) - \Sigma j_p\varpi_p.\Sigma j_p\,(1-\varpi_p)/\Sigma j_p \\
&\qquad = -\,\Sigma j_p j_q\,(\varpi_p-\varpi_q)^2/\Sigma j_p,
\end{aligned}
$$

and since the j's agree in sign with the κ's it follows that V is intermediate in magnitude between I and J. In other words the secondary surface lies entirely between these two spheres. As these spheres do not differ greatly in curvature it is evident that the secondary surface does not depart greatly from the spherical form and that the Petzval theorem gives a reliable guide to its position even for large angles of view. The primary surface lies between the surfaces constructed by reducing the distances of these spheres from the lens vertex in the ratio $\cos^2\psi : 1$. These limiting surfaces associated with the primary foci are not of course symmetrical with respect to a transverse plane, but they both touch the lens on the axis.

As an example, consider an objective constructed from a positive lens of power 2·5 and refractive index 1·5 and a negative lens of power − 1·5 and refractive index 1·6.

$$\varpi = \frac{2{\cdot}5}{1{\cdot}5} - \frac{1{\cdot}5}{1{\cdot}6} = {\cdot}73916,$$

$$\frac{1}{\mu} = \frac{5-2{\cdot}5}{7{\cdot}5-4} = {\cdot}71429.$$

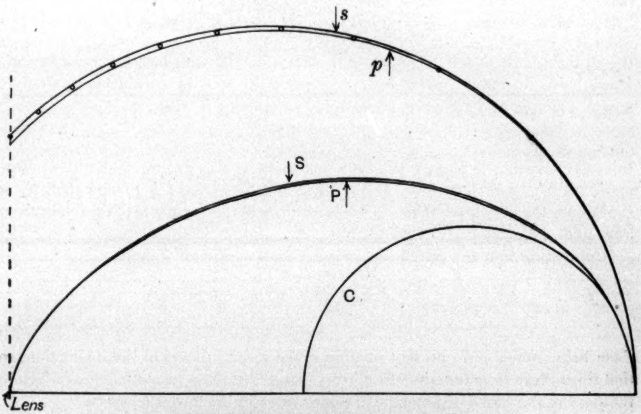

Fig. 3. *p* circle representing Petzval limit for secondary foci.
s circle representing "slowness" limit for secondary foci.
o actual points on secondary surface.
P and *S* the primary focal limits corresponding to *p* and respectively.
C the circle giving the paraxial curvature of *P*.

Fig. 3 shows sections of these spheres and of the corresponding primary surfaces together with points on the actual secondary focal surface found by direct calculation from Coddington's formula. The primary points lie between the two limiting surfaces in the same relative position as the secondary points, but they are not marked in the diagram owing to the smallness of the separation of these surfaces. Figures for a number of rays are given in the following table.

$\cos\psi$	I	V	J	$(V - I)\,10^4$	$(V - J)\,10^4$
1·0	1·0	1·0	1·0	0	0
·9	1·0778	1·0776	1·0760	− 2	16
·8	1·1663	1·1658	1·1623	− 5	35
·7	1·2676	1·2660	1·2604	− 16	56
·6	1·3836	1·3802	1·3723	− 34	79
·5	1·5168	1·5103	1·5	− 65	103
·4	1·6698	1·6585	1·6458	− 113	127
·3	1·8450	1·8266	1·8117	− 184	149
·2	2·0451	2·0166	2·0	− 285	166
·1	2·2719	2·2300	2·2122	− 419	178
0	2·5268	2·4677	2·4495	− 591	182

ABSTRACTS OF PATENT SPECIFICATIONS

200488*. Lenouvel, L. TESTING OPTICAL SYSTEMS.

A ruled screen is placed at the focal plane of the system, and a superposed image is produced by reflecting back the emergent light. Defects in performance are indicated by various types of distortion effects or irregularities in the pattern observed when looking through the screen.

200664. Hadsel, A. D. SURVEYING INSTRUMENTS.

The instrument is designed for laying down upon a plan the relative positions of stadia rods. A vertical hair-line is brought into coincidence with the rod, and adjusted in position relatively to a pair of horizontal lines until the latter subtend a definite length on the rod. The point immediately below the vertical hair-line then represents the position of the rod.

200685. Beck, C., and another. EYEPIECES.

Achromatic eyepieces are so constructed that the focal plane is at the lower surface of the lower element. An alteration of power is obtained by the replacement of the upper element, without displacing the focal plane.

200777. Taylor, W., and others. MICROSCOPES.

A set of optical and mechanical parts similar to those described in Specification No. 196948 is employed to build up a series of microscopes illustrative of various constructional types of instrument.

* Specification published before acceptance.

201087. Heimstädt, O. MICROSCOPES.

In order to obtain a stereoscopic effect in a binocular instrument having only one primary objective, the separation of the cones of light is effected by a pair of prisms or a glass plate furnished with a permeable reflecting surface which is thicker on one side of the centre than the other. The effect is to displace the optical centres of gravity of the two cones in opposite directions.

201414. Beck, C., and others. MICROSCOPES.

A reflector for dark ground illumination consists of an annulus with its back face silvered, and its surfaces ground to spherical curvatures so calculated as to focus upon the object a parallel beam of light having its centre portion stopped out.

201709. Truscott, E. F. GRINDING LENSES.

A lens-grinding machine consists of a frame carrying a series of spindles frictionally driven from a main shaft, each blank being placed between a pair of tools, one driven by a crank-pin on one of the spindles, and one supported on a spigot below it. The frame itself tends to rotate, but is checked by a band brake.

202023. Leitz, E. MICROSCOPES.

In a stereoscopic double microscope, the objectives are convergently directed, while the eyepieces are parallel, and adjustable for interocular distance. The images are erected by prism systems.

202803. Casella & Co., Ltd., and another. THEODOLITES.

The scale is marked on the inner face of a flange on a circular disc, both sides being read simultaneously by means of two microscope objective and prism systems in connection with a single eyepiece, which is situated upon the axis of the circle.

203600. Casella & Co., Ltd., and another. MICROMETER EYEPIECES.

The cross webs are mounted upon a sliding frame having a screwed extension which works within a tubular nut integral with the micrometer head. The graduated drum is located within the eyepiece, so that it can be read without removing the eye from the instrument.

204002. Zeiss, C. LENSES; PRISMS.

Optical elements are made from crystallized fluoride of sodium or lithium, as a substitute for fluorspar.

204666. Zeiss, C. REFRACTOMETERS.

The prisms of dipping refractometers are so constructed as to permit the adjustment to be tested by using a body differing considerably in refractive index from the prism. For instance, the face from which the light emerges may consist of two surfaces at an angle to each other, one being the normal working face and the other serving for adjustment purposes.

205381. Lamplough, F. E. LIGHT FILTERS.

Screens or reflectors for producing daylight effects are made from glass containing gold and copper and one or more of the ingredients cobalt, nickel, and manganese.

R. J. T.